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Computer solutions to depletion drive hydrocarbon systems

Tu Kao Chen

COMPUTER SOLUTIONS TO DEPLETION DRIVE
HYDROCARBON SYSTEMS

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Approved by

G. E. Vaughn Jr. (advisor) R. E. Carlile

B. E. Gillett M. R. Beveridge

ABSTRACT

Three computer analyses of oil production by depletion drive have been developed. These analyses, Tarner's method of depletion drive oil production prediction, depletion drive performance productions of Schilthuis, and depletion drive calculations by a finite difference material balance, have been programmed for computers having Fortran IV compilers and a minimum of 40 K bytes of core storage capacity. Modifications have been incorporated in the last two techniques for (a) constant volume injection of produced gas, (b) the presence of a gas cap, (c) gas-cap injection of produced gas volumes, (d) varying water encroachment and production, and/or, (e) varying sweep efficiencies and productivity indices, subject to specific restrictions and constraints.

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NOMENCLATURE

Standard Symbol	Description	Program Coding
B_g	gas formation volume factor	BG
B_o	oil formation volume factor	BØ
B_t	total (two phase) formation volume factor	BT
ΔG_i	gas injection during the interval	
G_i	cumulative gas injection	GCI
ΔG_p	gas produced during interval	DG & DG1
G_p	cumulative gas produced	CGP
m	ratio initial reservoir free gas volume to initial reservoir oil volume	GC
N	initial oil in place	RES
N_e	cumulative oil influx	EN2
ΔN_e	oil flux (encroachment)	ENU
N_p	cumulative oil produced	EN
ΔN_p	oil produced during an interval	DNP
P	reservoir pressure	PSIA
P_a	atmospheric pressure	PA
r_e	external boundary radius	
r_w	well radius	
J	production index	PI

R	producing gas oil ratio	GØR
R_p	cumulative gas oil ratio	RN
R_s	solution gas oil ratio	RS
S_g	gas saturation	SG
S_o	oil saturation	SØ
S_w	water saturation	SW
S_L	liquid (oil and water) saturation	SL
T_f	formation temperature	TF
T_a	atmospheric temperature	TA
V	volumetric velocity	
W_e	cumulative water influx	
W_p	cumulative water produced	
ΔW_e	water influx during an interval	DWE
ΔW_p	water produced during an interval	DWP
Z	gas deviation factor	Z
μ_g	gas viscosity	UG
μ_o	oil viscosity	UØ

I. INTRODUCTION

The purpose of this investigation is to use the high speed digital computer to calculate the future performance of depletion-drive hydrocarbon systems employing previously proven techniques. Three depletion drive calculations have been adapted to computer solution. These techniques are:

1. Tarner's method of depletion drive oil production (6);
2. Depletion drive performance predictions of Schilthuis (2); and,
3. Depletion drive calculation by a finite difference material balance equation as proposed by Muskat (8).

Each method is based on a material balance trial-and-error technique which yields an iterated cumulative oil production approximation at each pressure stage of depletion.

In the past, these depletion-drive calculations have been solved by laborious hand calculations. Such calculations are time consuming, and the results have been found to be quite sensitive to numerous mechanical and tedium errors. With the advent of high-speed digital computers, it is now practical to adapt such solutions to machine calculation thus eliminating the majority of the mechanical errors of roundoff while providing rapid and incremental comparisons between techniques.

In the Schilthuis and finite difference techniques, five modifications have been incorporated in the mainline programs; (a) constant production gas injection considerations, (b) considerations of the presence and effects of a gas cap on the drive mechanisms, (c) injections of produced gas into the gas-cap, (d) varying water encroachment and production, and (e) varying sweep efficiencies.

The analyses have been subdivided into two principal parts. First, the theories which are related to the fundamental concepts of depletion drive performance are reviewed, and, second, the three depletion drive solutions are modified and adapted to computer solution.

II. REVIEW OF LITERATURE

In 1929, Coleman, Wilde and Moore (1) undertook an investigation on the mechanisms affecting the predictions of the production of oil and gas. The most important result of their work was presented in an equation defining the relationship between the reservoir pressure, the quantities of oil and gas produced, the oil and gas content of the reservoir, and the properties of the entrained reservoir fluids.

In 1936, Schilthuis (2) presented a modified form of the equation given by Coleman, Wilde and Moore, and presented a set of formulas which approximated the reservoir energy changes which could be anticipated to occur during the course of production and pressure decline. Simultaneously with Schilthuis' work, Katz (3) proposed a tabulation means for the evaluation of oil in place. In 1945, Pirson (4) showed Schilthuis' and Katz's methods to be equivalent and pointed out the advantages of their material balance equation when used in analytical studies.

The initial investigator to propose a trial-and-error solution to the depletion drive problem was Babson (5) who suggested, in 1944, a rather laborious trial-and-error procedure in which increments of oil production are assumed and the value then balanced by trial-and-error until the result fell within an acceptable margin. Almost simultaneously, Tarner (6) made a contribution to the solution of this problem which is much more direct in its approach. His technique consisted of a correlation between assumed free gas production for three assumed increments of oil production compared with three instantaneous gas-oil ratios which would arise from the produced gas volumes. The point at which the two gas production criteria were simultaneously satisfied was accepted as the correct oil production for the imposed pressure drop.

In 1946, a gas-contacting efficiency was proposed as a qualifying constraint to these techniques in the form of a conformance factor, by E. C. Patton (7). This efficiency factor was proposed to represent the departure from uniform dissemination of the injected gas throughout the actual reservoir.

III. THEORY

The principal hypothesis of a depletion-drive calculation is the computation of incremental pressure decline and gas-oil ratios as a function of cumulative production. This is accomplished by the solution of the following four simultaneous equations.

1. The material balance equation equating original oil in place, N, with oil produced, N_p, water produced, W_p and encroached water, W_e*.

$$N = \frac{N_p(B_o+B_g\{R_p-R_s\})-(W_e-W_p)}{B_g(R_s^o-R_s)-(B_o^o-B_o)+mB_o^o(B_g/B_g^o-1)} \tag{1}$$

2. The instantaneous gas-oil ratio equation which equates the unit gas production per unit liquid production.

$$R = R_s + \frac{B_o K_g \mu_o}{B_g K_o \mu_g} \tag{2}$$

3. The cumulative gas production:

$$G_p = \Sigma\Delta N_p R = N_p R_p \tag{3}$$

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* Symbols are defined in the nomenclature

4. The productivity-index (PI) equation:

$$PI = (PI)_o K_o \frac{(B_o \mu_o)_o}{B_o \mu_o} \tag{4}$$

The Material Balance Equation:

The material balance equation expresses the relationship which must exist at all times in an oil and gas reservoir produced under or near equilibrium conditions. If N is the total oil volume initially in place at initial pressure P_o, then NB_o is the reservoir volume occupied by all the original stock-tank oil containing its complement of dissolved gas. mNB_o is the reservoir volume occupied by the gas cap under pressure P_o.

After N_p units of stock tank oil have been produced, the field pressure is reduced to pressure P_i, and the reservoir assumes a new equilibrium condition. The following material symbolizations will be assumed to be in effect during each equilibrium period.

$(W_e - W_p)$: the reservoir volume invaded by water.

$(N-N_p)B_o$: the reservoir volume of remaining stock tank oil including its complement of dissolved gas under pressure P_i.

mNB_oB_g/B_g^o: the new volume of the gas cap resulting from the expansion of the gas between pressure P_o

and P_i under the assumption that no gas was produced from the gas cap.

Considering that a material balance on the gas volume and that the net space vacated by the oil and gas produced must be exactly filled by the gas that came out of solution is excess of the net gas produced, the following are obtained:

$N_pB_o^o$: the space vacated by the produced oil.

$(N-N_p)(B_o^o-B_o)$: the volumetric shrinkage of the remaining oil.

$mNB_o^o(B_g/B_g^o-1)$: the gas expansion of the gas cap.

(W_e-W_p): the net water encroachment during P_o to P_i.

The volume of gas at standard conditions coming out of solution in excess of the net gas produced will equal the sum of the gas in solution in N_p units of oil produced $(N_pR_s^o)$. Thus, $(N-N_p)(R_s^o-R_s)$ is the gas coming out of the solution from the oil remaining in the reservoir and N_pR_p is the net produced gas.

The volume of excess librated gas at reservoir conditions must be equal to the net volume vacated by the produced oil and gas. Thus,

$$N_pB_o^o+(N-N_p)(B_o^o-B_o)-mNB_o^o(B_g/B_g^o-1)-(W_e-W_p) = B_g(N_pR_s^o+(N-N_p)(R_s^o-R_s)-N_pR_p) \quad (5)$$

or, upon rearrangement, the original oil in place is found to be

$$N = \frac{N_p(B_o+B_g(R_p-R_s))-(W_e-W_p)}{mB_o^o(B_g/B_g^o-1)+B_g(R_s^o-R_s)-(B_o^o-B_o)} \tag{6}$$

Letting $$B_t = B_o+B_g(R_s^o-R_s)$$

and, $$B_t^o = B_o^o \tag{7}$$

then Eq. (6) can be rewritten as

$$N = \frac{N_p(B_t+B_g(R_p-R_s^o))-(W_e-W_p)}{mB_t(B_g/B_g^o-1)+(B_t-B_t^o)} \tag{8}$$

<u>Instantaneous Producing Gas-Oil Ratio Equation:</u>

The instantaneous producing gas-oil ratio equation is derived from Darcy's Law (6) which states

$$V = \frac{K}{\mu}\frac{dP}{dr}$$

or, the flow rate, q, is

$$q = \frac{KA}{\mu}\frac{dP}{dr} \quad . \tag{9}$$

For radial flow, the area A, is equal to 2 rh, yielding

$$q = \frac{K(2\pi rh)}{\mu}\frac{dP}{dr} \quad . \tag{10}$$

Integrating between the limits of well radius, r_w, and outer radial limit r_e,

$$q\int_{r_w}^{r_e}\frac{dr}{r} = \frac{2\pi Kh}{\mu}\int_{P_w}^{P_e} dP$$

or

$$q = \frac{2\pi Kh(P_e - P_w)}{\mu \ln(r_e/r_w)} \tag{11}$$

This is the equation for volume rate of flow of a non-compressible fluid through porous media. As oil is, for the most part, a relatively non-compressible fluid, this equation can be considered to express the rate of oil efflux from the sandface into the well bore. To convert to a volume rate of residual oil flowing, the shrinkage or formation volume factor must be employed:

$$q_o = \frac{2\pi K_o(P_e - P_w)}{\mu_o B_o \ln(r_e/r_w)} \quad . \tag{12}$$

To obtain the equation for the volume rate of gas flowing when the gas is measured at standard conditions, Eq. (11) must be corrected for conditions of temperature and pressure to provide for flow of the compressible fluid in contrast to the assumed non-compressible liquid represented by Eq. (12). Thus,

$$q \frac{(P_e+P_W)}{2ZT} = q_g \frac{P_a}{T_a} \tag{13}$$

or,

$$q_g = \frac{K_g h(P_e-P_W)(P_e+P_W)T_a}{\mu_g P_a ZT \ln(r_e/r_W)} \quad . \tag{14}$$

Equation (14) expresses the volume rate flow of a compressible fluid through a porous medium at reservoir conditions. The gas-oil ratio can be written as follows from Eqs. (14) and (12)

$$\frac{q_g}{q_o} = \frac{K_g \mu_o (P_e+P_W) B_o T_a}{K_o \mu_g 2 P_a Z T} \quad . \tag{15}$$

This equation represents an average gas-oil ratio assumed to exist between reservoir pressure (P_e) and the wellbore pressure (P_W). The instantaneous producing gas-oil ratio at surface condition is obtained as

$$R = \frac{K_g \mu_o B_o P T_a}{K_o \mu_g Z P_a T} + R_s \quad . \tag{16}$$

Let

$$B_g = \frac{P_a T}{P T_a} Z$$

then, Eq. (16) becomes

$$R = R_s + \frac{B_o K_g \mu_o}{B_g K_o \mu_g} \quad . \tag{17}$$

Cumulative Gas Production:

Cumulative gas production is assumed to be a cumulative expression of the incremental gas productions as given by

$$G_p = \Delta N_{p1}R_1 + \Delta N_{p2}R_2 + \text{-----} + \Delta N_{pn}R_n = \sum_1^N \Delta N_p R \quad . \tag{18}$$

If $$N_p = \Delta N_{p1} + \Delta N_{p2} + \text{-----} + \Delta N_{pn} \tag{19}$$

and $$R_p = \frac{G_p}{N_p} \quad . \tag{20}$$

Thus, the cumulative gas production becomes

$$G_p = \sum_1^N \Delta N_p R = N_p R_p \tag{21}$$

Productivity Index:

By definition the productivity index is the stock tank barrels per day of production per unit pressure decrement. Thus,

$$PI = \frac{q_o}{\Delta P} = \frac{Kh}{\mu_o B_o \ln(r_e/r_w)} \tag{22}$$

and, for the liquid hydrocarbon phase,

$$(PI)_o = \left(\frac{K}{\mu_o B_o}\right)_o \frac{h}{\ln(r_e/r_w)}$$

where the subscript o represents the liquid phase hydrocarbon portion.

Or, upon rearrangement,

$$\frac{h}{\ln(r_e/r_w)} = (PI)_o\left(\frac{\mu_o B_o}{K}\right)_o \quad . \tag{23}$$

Substitution of Eq. (23) into Eq. (22) yields,

$$PI = (PI)_o K_o \frac{(\mu_o B_o)_o}{\mu_o B_o} \quad . \tag{24}$$

The four equations thus presented form the basis for the Tarner, Schilthuis, and finite difference techniques. Each technique will be discussed in detail in the following pages in relation to the specific alterations required on each method for computer adaptation.

IV. MAIN PROGRAM

The relative permeability data required in the instantaneous gas-oil ratio cannot be used directly in the programs without storing these data and forming some interpolation routine for values between those tabulated. A least square fit* has been used to find the correlation coefficients of K_g/K_o with S_o or S_L. A least square program equation $K_g/K_o = e^{f(S_L)}$ had been solved before the depletion drive analyses were attempted. This expression of relative permeability in polynomial form facilitates subsequent use of the permeability-saturation variations in the instantaneous GOR equations by providing an easily solvable polynomial which can be stored.

The polynomial resulting from the least square fit for the example considered has been found to be:

Oil :

$$\frac{K_g}{K_o} = e^{(12.84501-22.820311S_o+0.90475397S_o^2)} \quad (25)$$

Total liquid:

$$\frac{K_g}{K_o} = e^{(111.77865-451.90209S_L+626.46718S_L^2-300.663846S_L^3)} \quad (26)$$

Figure 1 shows the K_g/K_o vs S_o relationship calculated

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* See page 103

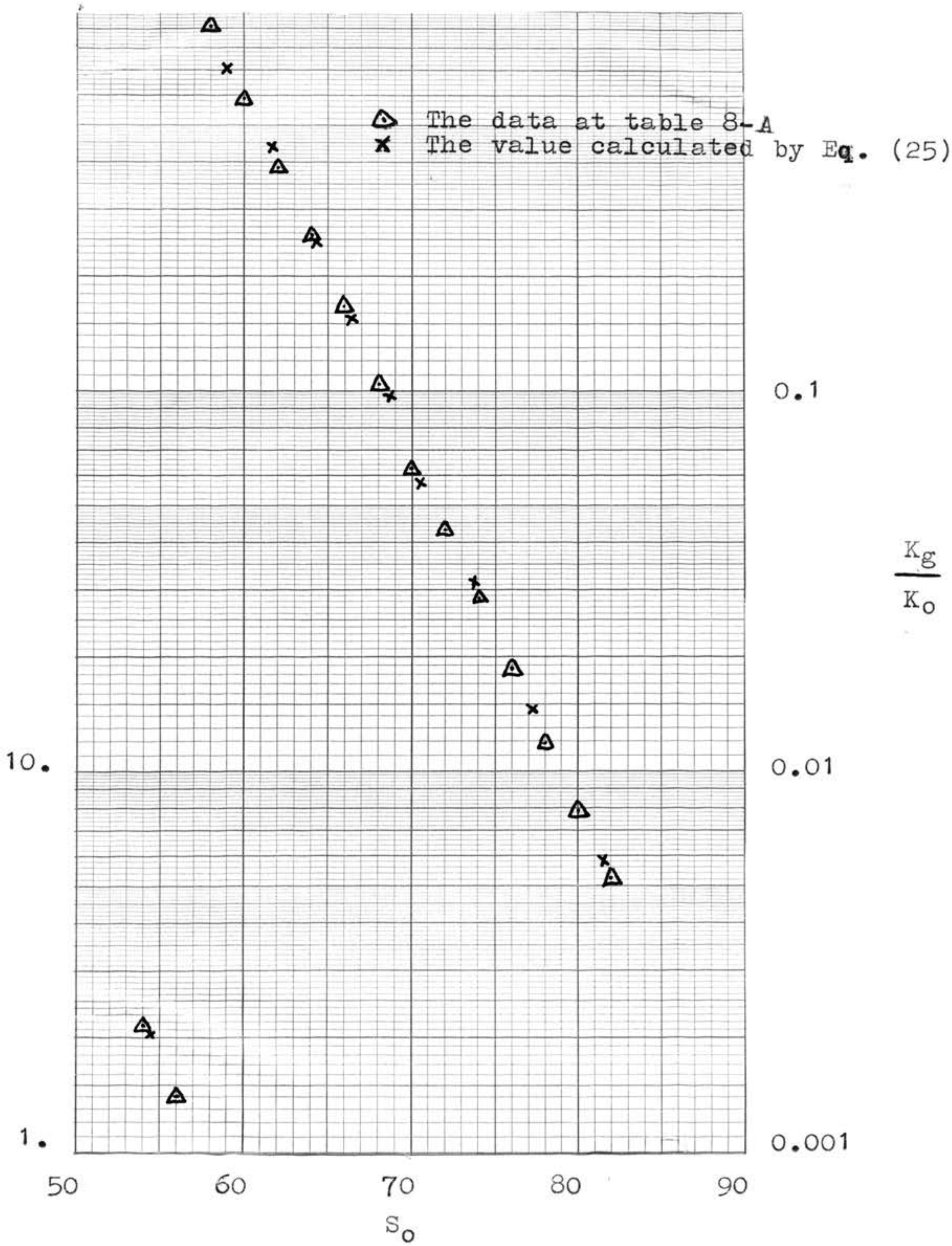

Figure 1 Relative permeability versus oil saturation from polynomial correlation.

from Eq. (25). The accuracy of this polynomial approximation is verified by data given Table 8-A.

The three depletion drive calculations were solved in the following order:

1. Tarner's method of depletion drive prediction;
2. Depletion drive calculation by means of the Schilthuis equation; and
3. Depletion drive calculation by the finite difference material balance.

A. Tarner's Method of Depletion-drive Prediction

For simplification it will be assumed that $W_e = 0$, $W_p = 0$, and $m = 0$. With these assumptions, Eq. (6) may be rewritten as

$$N = \frac{N_p(B_o + B_g\{R_p - R_s\})}{B_g(R_s^o - R_s) - (B_o^o - B_o)} \tag{27}$$

which facilitates machine handling. For a stated cumulative production N_p, the cumulative produced gas G_p may be calculated by using Eq. (21) and Eq. (27) as

$$G_p = N_pR_p = N\{(R_s^o - R_s) - (B_o^o - B_o)/B_g\} - N_p(B_o/B_g - R_s) \tag{28}$$

and,

$$G_p = \int_0^{N_p} R\,dN_p \quad . \tag{29}$$

The gas production increment (ΔG_p) between two oil productions N_p^2 and N_p^1 can be evaluated from two different forms of G_p as represented by Eq. (28) and Eq. (29) as

$$\Delta G_p = G_p^2 - G_p^1$$

$$= N(R_s^1 - R_s^2 - \frac{B_o - B_o^2}{B_g^2} + \frac{B_o - B_o^1}{B_g^1}) - N_p^2(\frac{B_o^2}{B_g^2} - R_s^2) + N_p^1(\frac{B_o^1}{B_g^1} - R_s^1) \qquad (30)$$

$$\Delta G_p = G_p^2 - G_p^1 = (R_1 + R_2)(N_p^2 - N_p^1)/2 \quad . \qquad (31)$$

In solving for G_p from Eq. (31), the K_g/K_o relationship in Eq. (17) must be available. Since K_g/K_o is a function of oil saturation and/or liquid saturation,

$$S_o = (1-S_w)\frac{(N-N_p)B_o}{NB_o^o} \qquad (32)$$

where,

$$S_L = S_o + S_w \quad ,$$

then G_p can be determined if the N_p^2 and N_p^1 are available. The general calculation procedures are as follows:

a. Assume the previous incremental conditions of N_p, G_p, and P are known. Initial conditions are assumed as $N_p^1 = 0$, $G_p^1 = 0$, $P = P_1$.

b. The field pressure is reduced to an assigned pressure, P_2.

c. The stock-tank oil production is estimated as N_p^2 during the pressure drop from P_1 to P_2.

d. The ΔG_p is calculated by Eq. (30) and Eq. (31). If the difference between the two computed ΔG_p values is less than an imposed error, say 1%, then the value of N_p^2 is assumed to be the correct cumulative production at pressure P_2. If not, another value of oil production is estimated and steps b through d are repeated until the error between the calculations is less than the imposed error.

The example problem solved by Pirson (4) had been used to check the programs. Table 1 shows the comparison of results obtained by Pirson and those obtained by the program.

The flow chart for the general Tarner's depletion-drive solution is given as follows:

Figure 2

Flow Chart of Tarner's Method

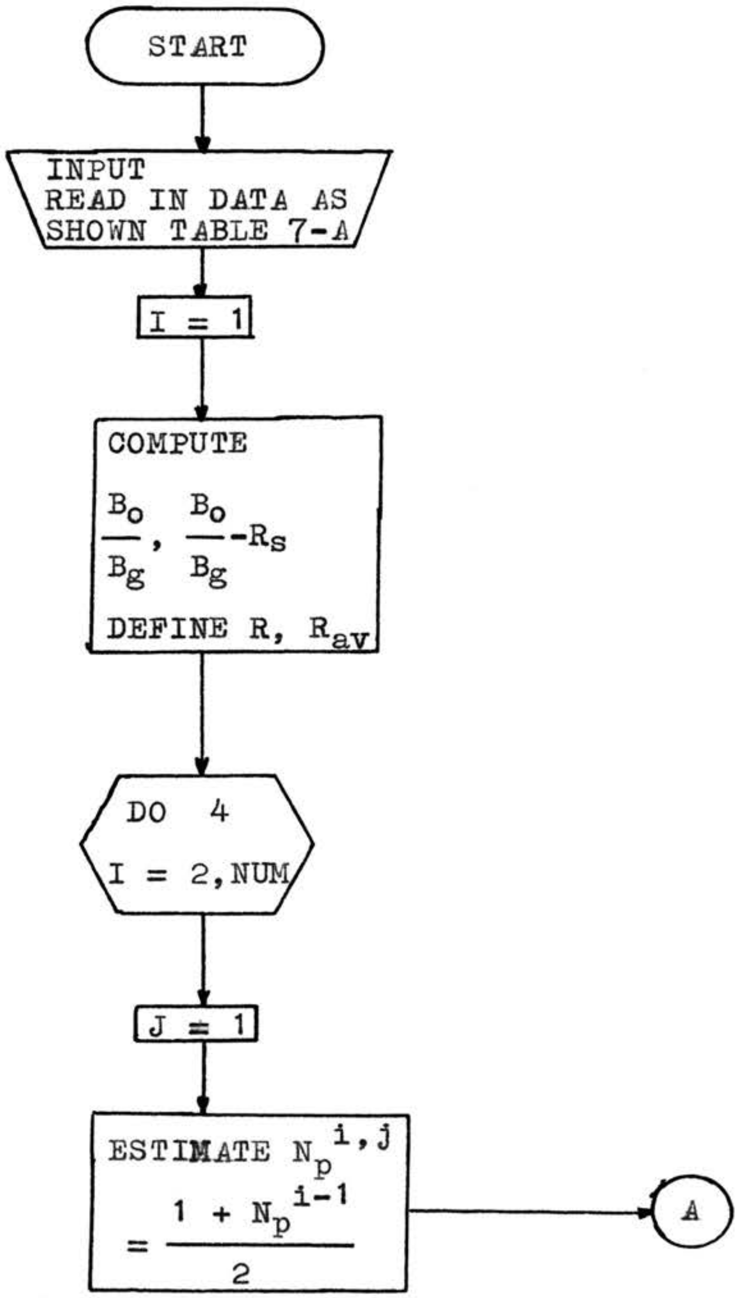

Figure 2

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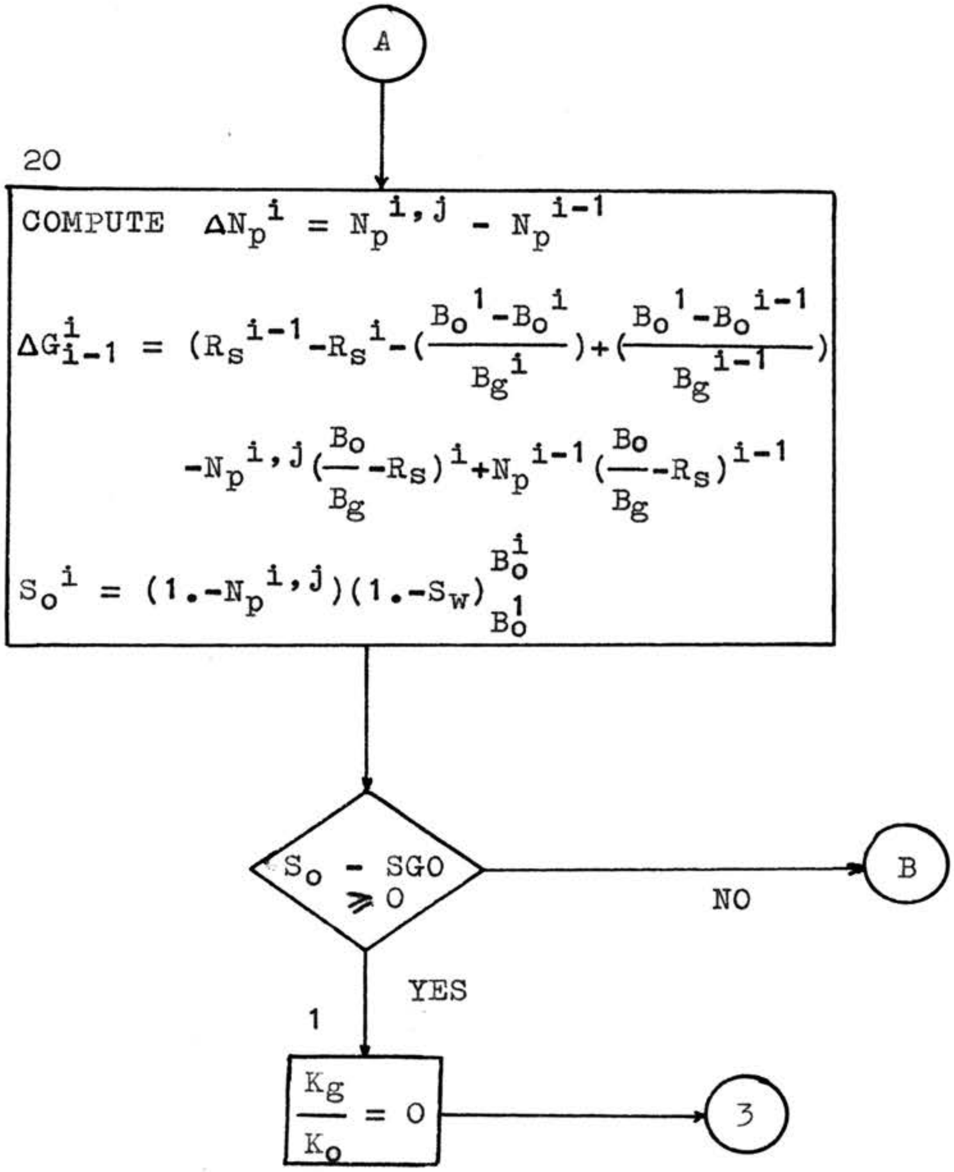

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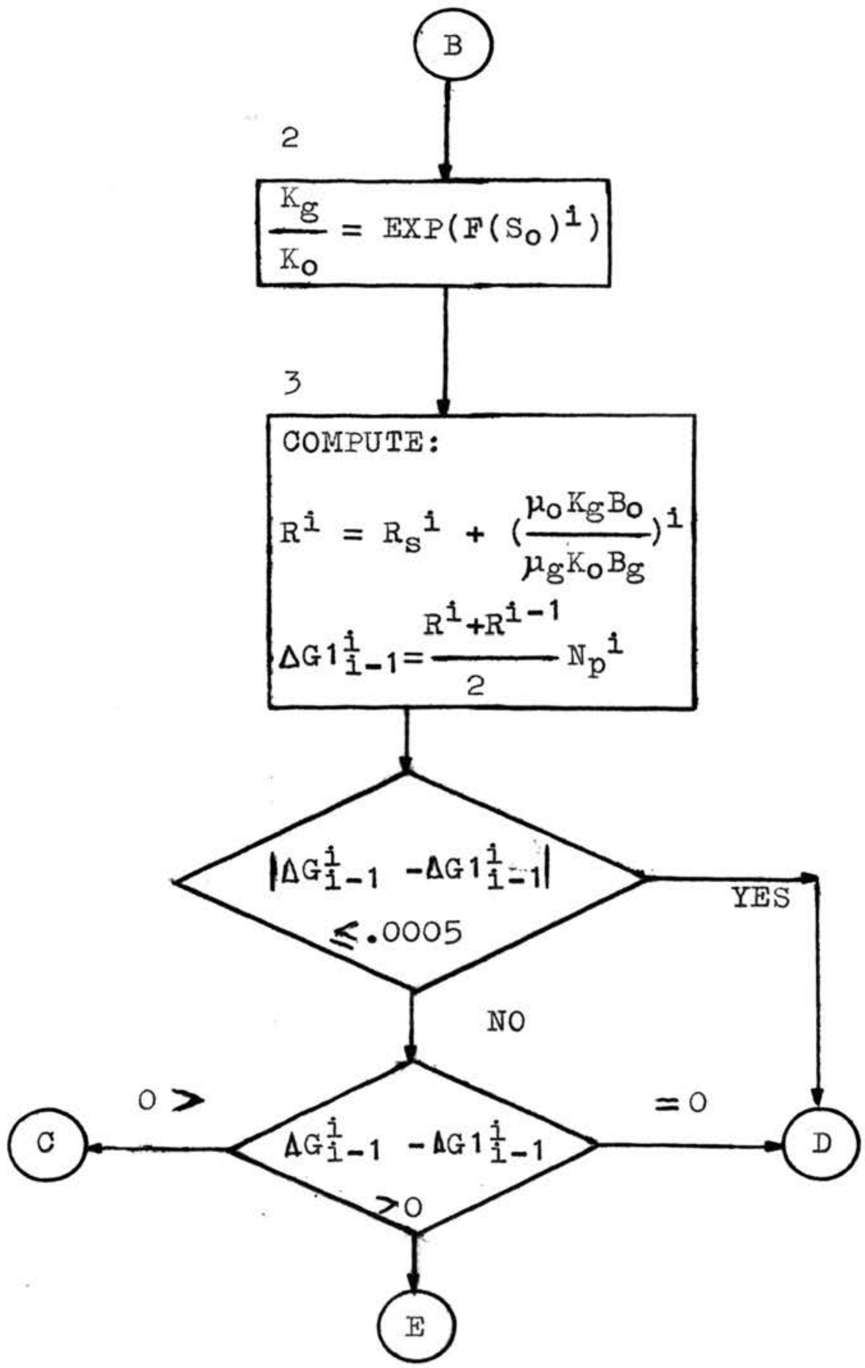

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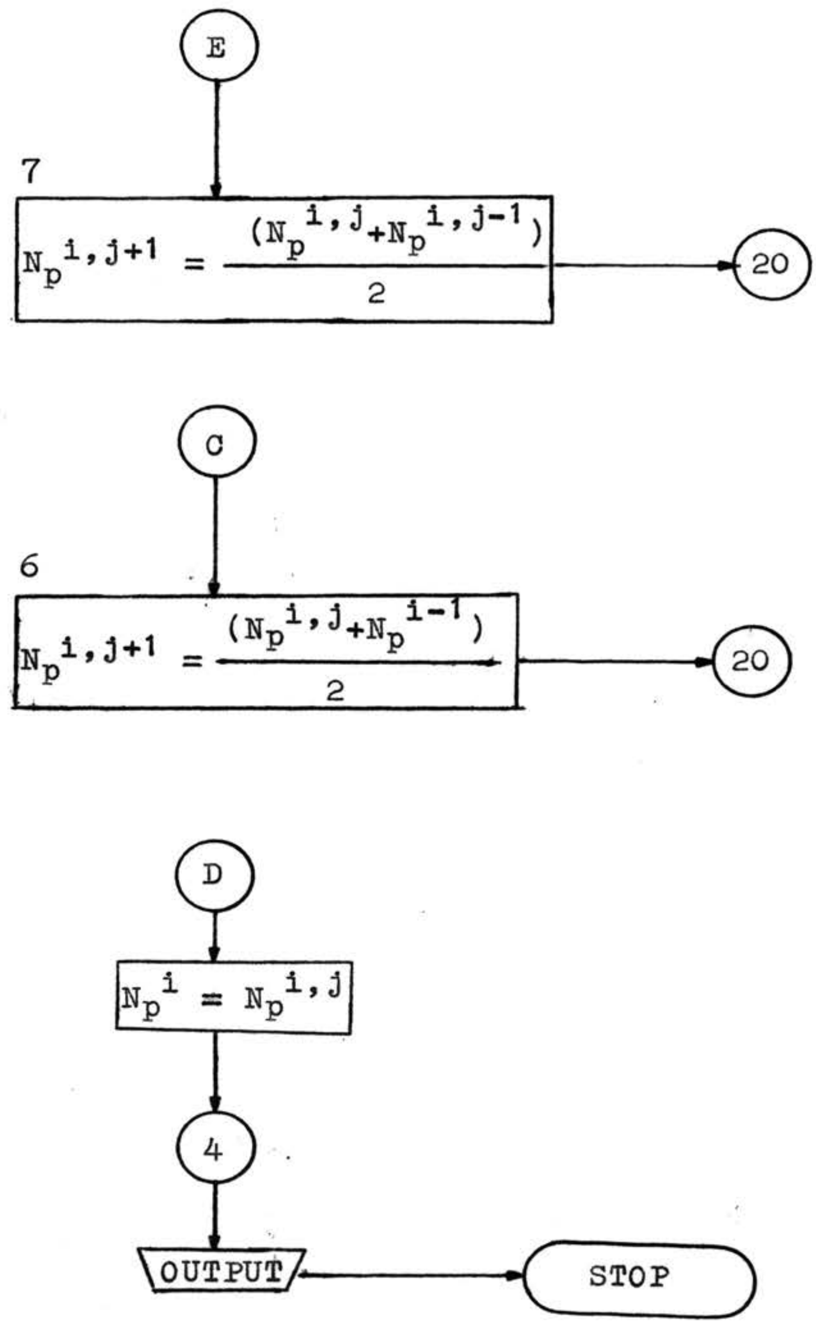


TABLE 1

Depletion drive calculation by Tarner's method

Pressure	Differential gas production, fraction of N		Cumulative stock tank oil production, fraction of N	
	Pirson	Program	Pirson	Program
2000	0	0	0	0
1850	1.22	1.2281	0.0143	0.0144
1700	1.57	1.5636	0.0336	0.0338
1550	1.89	2.0173	0.062	0.0605
1400	2.64	2.5623	0.095	0.0931
1250	4.37	3.4794	0.139	0.1298
1100	3.92	4.7643	0.168	0.1661
950	5.85	5.9879	0.197	0.1956
800	7.10	7.0583	0.219	0.2185
650	7.30	7.3225	0.234	0.2353
500	8.15	8.1685	0.247	0.2497
350	9.09	9.0863	0.260	0.2631
200	10.73	10.6757	0.273	0.2773
100	8.96	9.1964	0.284	0.2898
14.4	14.60	14.3768	0.311	0.3180

The general Tarner's depletion-drive program is presented. The required coding and variable input/output specifications are clarified by comment cards in the program. Additional comments and clarifications have been provided on the program adjacent to the point of initiation of each operation.

B. Depletion drive by Schilthuis:

Assuming $W_e = 0$, $W_p = 0$ and, $m = 0$, Eq. (8) may be rewritten as

$$N = \frac{N_p\left\{B_t + B_g(R_p - R_s^o)\right\}}{B_t - B_t^o} . \qquad (34)$$

For $N = 1$, the cumulative oil production N_p can be treated as a fraction which expedites the calculations.

The Schilthuis modifications to Equations (5) through (24) for gas injection, gas-cap, gas-cap injections, and water encroachment are:

1. When a constant percentage (I) of the produced gas is injected back into the reservoir and is uniformly dispersed throughout the reservoir fluids, the net cumulative gas production may be written as:

   $$G_p = \Sigma\Delta G(1-I)$$

   with the gas-oil ratio becoming

   $$R_p = \frac{\Sigma\Delta G(1-I)}{N_p} . \qquad (35)$$

   Substituting Eq. (35) into Eq. (34) yields:

   $$N = \frac{N_p(B_t + B_g(\Sigma\Delta G(1-I)/N_p - R_s^o))}{B_t - B_t^o} , \qquad (36)$$

   which expresses the desired material balance equation for injected gas considerations.

2. For the presence of a gas-cap, knowing the original volume of the gas-cap and the ratio (m) of this volume to that of the original oil in place, Eq. (34) can be modified to

$$N = \frac{N_p\{B_t+B_g(R_p-R_s^o)\}}{(B_t-B_t^o)+mB_o^o(B_g/B_g^o-1)} \qquad (37)$$

which now considers the oil in place with an adjacent gas cap.

3. For gas cap injection of a fraction of the produced gas without dispersion into the oil zone, the term

$mB_o^o(B_g/B_g^o-1)+B_g\sum_o^i \Delta GI$

is added to the denominator in Eq. (34) yielding

$$N = \frac{N_p\{B_t+B_g(R_p-R_s^o)\}}{(B_t-B_t^o)+mB_o^o(B_g/B_g^o-1)+B_g\sum_o^i \Delta GI} \quad . \qquad (38)$$

4. For water encroachment (W_e) and water production (W_p), the rate of the net water encroachment, (W_e-W_p), modifies Eq. (34) as follows:

$$N = \frac{N_p\{B_t+B_g(R_p-R_s^o)\}-(W_e-W_p)}{B_t-B_t^o} \quad . \qquad (39)$$

The encroaching water, W_e can be approximated by any one of many available techniques. The Schilthuis procedure is used herein. If two or more upper conditions can be presented at same time, the term (W_e-W_p) can be added to

Eq. (38) to yield

$$N = \frac{N_p\left\{B_t+B_g(R_p-R_s^o)\right\}-(W_e-W_p)}{(B_t-B_t^o)+mB_o^o(B_g/B_g^o-1)+B_g\sum_o^i \Delta GI} \quad . \tag{40}$$

The calculations for the evaluation of oil production by Schilthuis' technique is as follows:

a. Assume that the previous incremental conditions of N_p, G_p, and P are known. If initial conditions are assumed, $N_p^1 = 0$, $G_p^1 = 0$, $P = P_1$.

b. It is assumed that the field pressure reduces to a pressure, P_2.

c. An estimate of the cumulative oil production N_p at P_2 is made as a fraction of N.

d. The insitu oil saturation and liquid saturation are determined and the corresponding K_g/K_o value is evaluated from the polynomials previously determined.

e. The produced gas-oil ratio and the material balance equation are evaluated from Eq. (17).

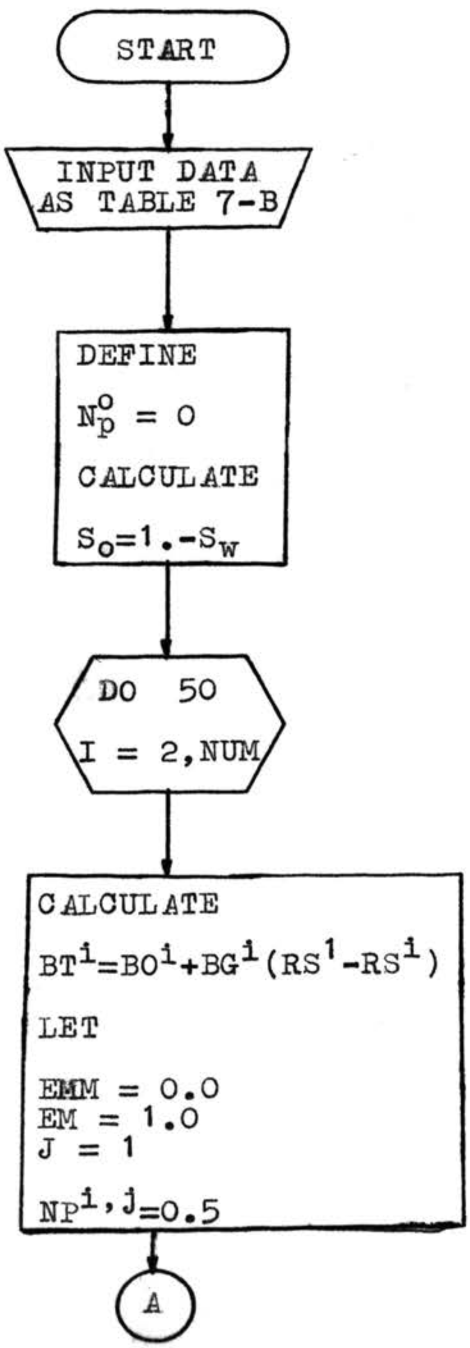
f. If the computed value of N is 1. or between 0.999 and 1.001 (arbitrary), the N_p value estimated is accepted as the cumulative oil production to pressure P_2. Otherwise, another value of N_p is estimated and steps (b) through (f) are repeated until the desired accuracy is obtained.

To provide for the four modifications desired in the Schilthuis technique, Equation (40) was adopted for the trial-and-error rectifications of $N_p = f(P)$.

The flow chart for the general Schilthuis depletion-drive program is given on page 28. The general Schilthuis program is given in the appendix. Comment cards incorporated in the program clarify the coding, input, and output declarations to assist in the use of the program. The example by Pirson was again used as a check and is listed in Table 2. The accuracy of these results by computer computation is deemed superior to those by Pirson.

Figure 3

Flow Chart of Schilthuis Equation



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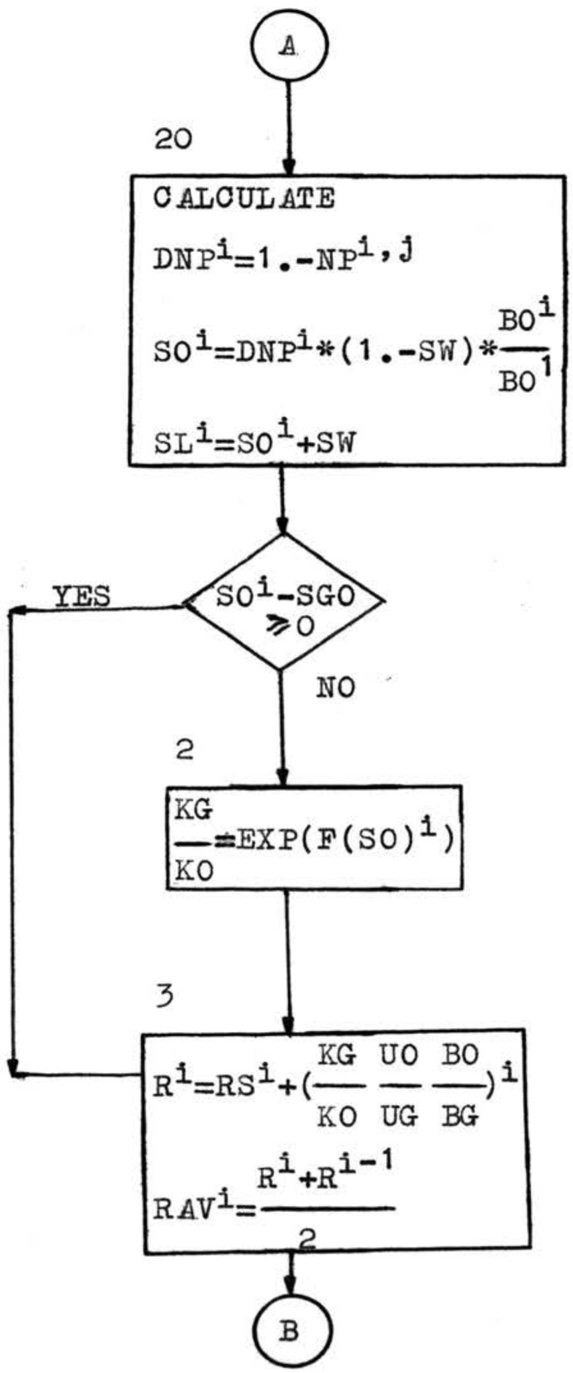

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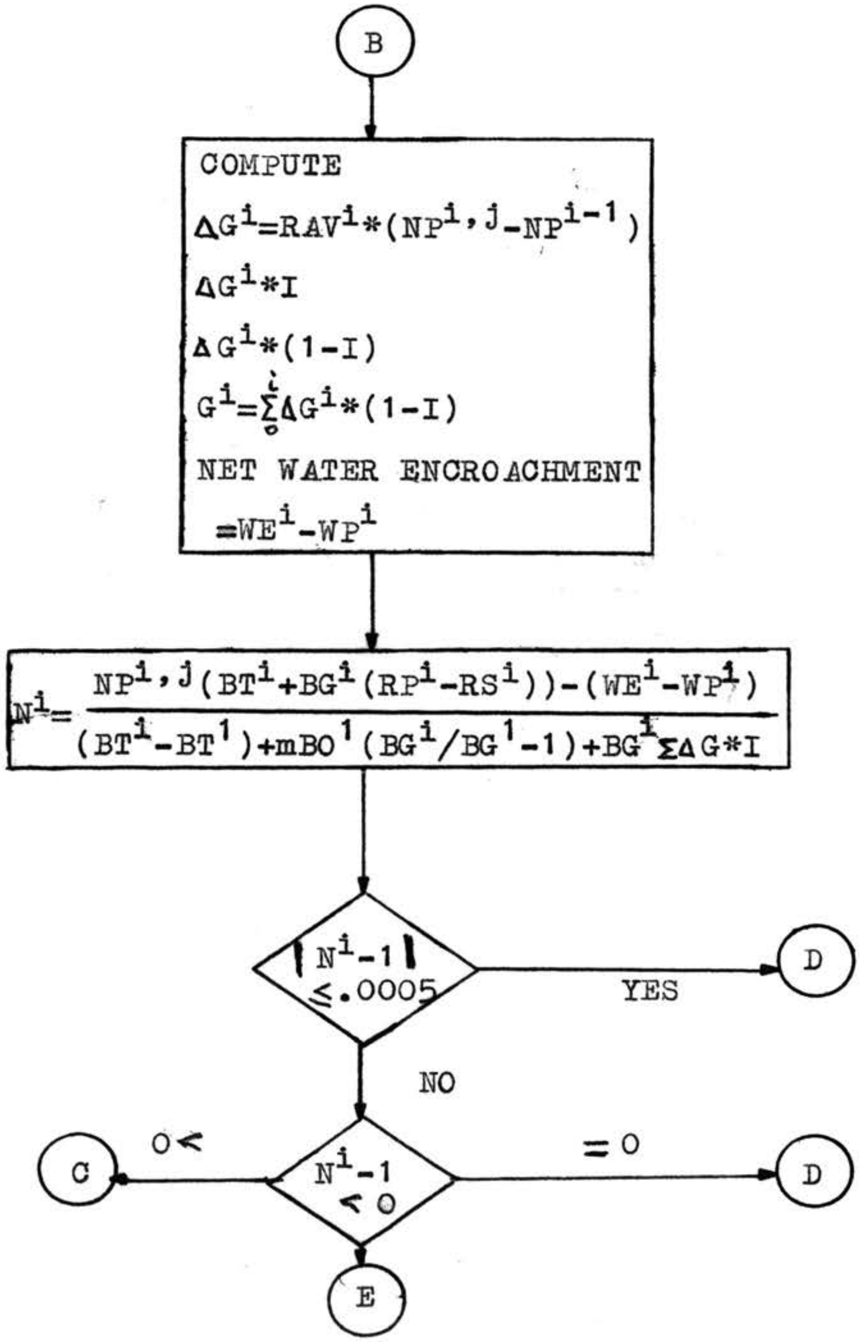

Figure 3

(continued)

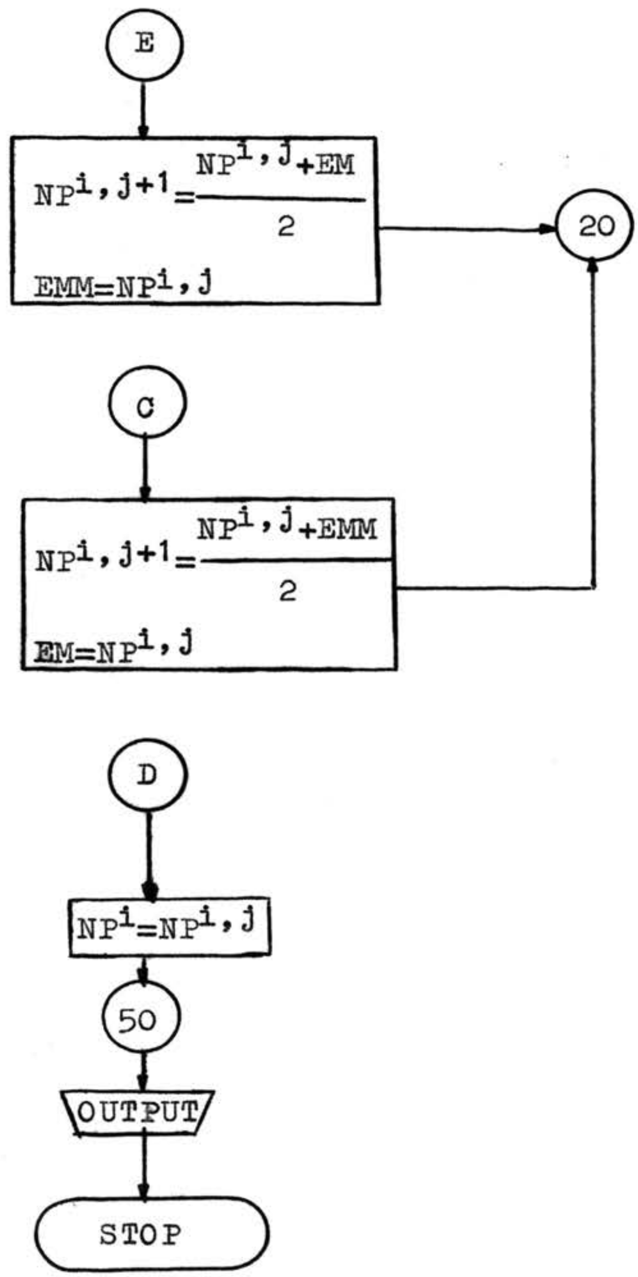

TABLE 2

Depletion drive calculation by means of Schilthuis equation

Pressure	N_p		$1-N_p$		S_o		S_L	
	Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
1850	.0142	.0144	.9868	.9856	.976	.974	.976	.974
1700	.034	.0338	.966	.9662	.943	.9434	.943	.9434
1550	.06	.0605	.94	.9395	.908	.9062	.908	.9062
1400	.093	.0930	.907	.9070	.865	.8641	.865	.8641
1250	.13	.1299	.87	.8701	.819	.8187	.819	.8187
1100	.166	.1664	.834	.8336	.776	.7744	.776	.7744
950	.196	.1961	.804	.8039	.738	.7374	.738	.7374
800	.218	.2188	.782	.7813	.708	.7074	.708	.7074
650	.233	.2351	.767	.7649	.686	.6835	.686	.6835
500	.247	.249	.753	.7510	.663	.6622	.663	.6622
350	.260	.2618	.74	.7382	.641	.6399	.641	.6399
200	.2735	.2751	.7265	.7249	.615	.6140	.615	.6140
100	.286	.2868	.714	.7132	.592	.5912	.592	.5912
14.4	.311	.3130	.689	.6870	.543	.5414	.543	.5414

TABLE 2 (continued)

K_g/K_o		R		R_{av}		ΔN_p		G_p	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
0.0	0.0	83	83	85.5	85.5	.0142	.0144	1.21	1.2277
0.0	0.0	78	78	80.5	80.5	.0198	.0194	1.59	1.5637
0.0	0.0	73	73	75.5	75.5	.026	.0267	1.962	2.0161
.002	.002	84.7	84.6131	78.8	78.8066	.033	.0325	2.60	2.5637
.0054	.0053	104.8	104.2190	94.7	94.4161	.037	.0369	3.51	3.4807
.0138	.0137	156.3	155.5413	130.5	129.8801	.036	.0366	4.71	4.7484
.0305	.0303	248.7	248.1894	202.5	201.8652	.030	.0297	6.08	5.9879
.060	.0578	403.	376.0474	326.	312.1182	.022	.0226	7.17	7.0676
.1	.0967	529.	520.5754	466.	448.3113	.015	.0164	6.98	7.3332
.155	.1532	650.	650.2600	589.	585.4177	.014	.0139	8.25	8.1467
.25	.2486	777.	772.2766	713.	711.2683	.013	.0128	9.27	9.1166
.44	.4352	816.	825.0723	796.	798.6743	.0135	.0133	10.75	10.6269
.70	.7144	688.	752.3342	752.	788.7031	.0125	.0117	9.40	9.1945
2.0	2.1188	385.	346.3752	536.	549.3547	.025	.0262	13.40	14.3843

TABLE 2 (continued)

G_p		R_p		$R_p - R_s^o$		$(R_p-R_s^o)B_g$	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
1.21	1.2277	85.5	85.5	-2.5	-2.5	-.0167	-.0166
2.81	2.7913	82.6	82.6251	-5.4	-5.3749	-.039	-.0392
4.77	4.8074	79.6	79.4796	-8.4	-8.5204	-.069	-.0694
7.37	7.3711	79.3	79.2442	-8.7	-8.7558	-.079	-.0797
10.88	10.8518	83.8	83.5505	-4.2	-4.4495	-.043	-.0458
15.59	15.6002	93.9	93.7270	5.9	5.727	.070	.0682
21.67	21.5881	110.7	110.0840	22.17	22.0840	.318	.3092
28.84	28.6557	133.	130.9977	45.	42.9977	.765	.7310
35.82	35.9890	154.	153.0745	66.	65.0745	1.387	1.3666
44.07	44.1356	179.	177.2348	91.	89.2348	2.55	2.4986
53.34	53.2522	205.	203.3763	117.	115.3763	4.795	4.7304
64.09	63.8791	234.	232.1640	146.	144.1640	10.65	10.5240
73.49	73.0736	257.	254.7856	169.	166.7287	25.20	24.6842
86.89	87.4579	280.	279.4287	192.	191.4287	199.2	220.1429

TABLE 2 (continued)

B_t		$[B_t+B_g(R_p-R_s^o)]N_p$		$B_t-B_t^o$		N	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
1.287	1.2872	.01802	.0182	.018	.0183	1.001	.9977
1.312	1.3120	.0433	.0430	.043	.0430	1.007	.9999
1.346	1.3462	.0766	.0772	.077	.0773	.994	.9997
1.392	1.3910	.1222	.1220	.123	.1220	.994	.9998
1.452	1.4515	.183	.1826	.183	.1825	1.000	1.0004
1.534	1.5360	.266	.2670	.265	.2670	1.003	1.0000
1.654	1.6540	.3865	.3850	.385	.3850	1.003	1.0000
1.829	1.8290	.565	.5600	.560	.5600	1.009	1.0000
2.079	2.0790	.807	.8101	.810	.8100	.997	1.0001
2.520	2.5190	1.252	1.2495	1.251	1.2500	1.001	.9996
3.395	3.3960	2.13	2.1278	2.126	2.127	1.002	1.0004
5.745	5.7470	4.48	4.4769	4.476	4.478	1.002	.9998
11.702	11.7080	10.53	10.4374	10.433	10.4390	1.009	.9999
92.4	102.2	90.8	100.8895	91.1	100.9310	.997	.9996

C. Depletion-drive Calculation by a Finite Defference Material Balance:

The material balance may be written on the basis of one unit of oil originally in place, or $N = 1$. If it is assumed that there is neither a gas cap ($m = 0$) nor a water drive in effect ($W_e = 0$) and that water production is negligible ($W_p = 0$), then Eq. (6) may written as

$$1 = \frac{N_p\{B_o + B_g(R_p - R_s)\}}{B_g(R_s^o - R_s) - (B_o^o - B_o)} \quad . \tag{41}$$

Dividing numerator and denominator by B_g to relate gas volume to reservoir conditions yields

$$1 = \frac{N_p(B_o/B_g - R_s) + N_p R_p}{(B_o/B_g - R_s) - (B_o^o/B_g - R_s^o)}$$

or

$$\left(\frac{B_o}{B_g} - R_s\right) - \left(\frac{B_o^o}{B_g} - R_s^o\right) = N_p\left(\frac{B_o}{B_g} - R_s\right) + N_p R_p \quad . \tag{42}$$

At pressure P_i;

$$\left(\frac{B_o}{B_g} - R_s\right)^i - \left(\frac{B_o}{B_g^i} - R_s^o\right) = N_p^i\left(\frac{B_o}{B_g} - R_s^o\right)^i + \sum_o^i \Delta N_p R_{pav} \tag{43}$$

At pressure, P_{i+1} where $P_{i+1} < P_i$,

$$\left(\frac{B_o}{B_g} - R_s\right)^{i+1} - \left(\frac{B_o^o}{B_g^{i+1}} - R_s^o\right)$$

$$= (N_p{}^i + N_{pi}^{i+1})\left(\frac{B_o}{B_g} - R_s\right)^{i+1} + \sum_o^{i+1} \Delta N_p R_{pav} \quad . \tag{44}$$

Solving for ΔN_{pi}^{i+1}

$$\Delta N_{pi}^{i+1} = \frac{(1-N_p^i)\Delta_i^{i+1}(\frac{B_o}{B_g}-R_s)-B_o^o\Delta_i^{i+1}(\frac{1}{B_g})}{(\frac{B_o}{B_g}-R_s)^{i+1}+R_{pav}} \tag{45}$$

which equates incremental oil production to equivalent incremental balances on the reservoir fluids.

If the produced gas is reinjected by a constant fraction, I, Eq. (45) can be rewritten as

$$\Delta N_{pi}^{i+1} = \frac{(1-N_p^i)\Delta_i^{i+1}(\frac{B_o}{B_g}-R_s)-B_o^o\Delta_i^{i+1}(\frac{1}{B_g})}{(\frac{B_o}{B_g}-R_s)^{i+1}+R_{pav}(1-I)} . \tag{46}$$

The evaluation of performance under gas injection will consist essentially in the solving of the following simultaneous equations which apply to the conformable zone, e, of the reservoir.

<u>Saturation equation in the conformance zone:</u>

$$(S_L)_e = S_w + \frac{(e-N^e)B_o}{eB_o^o}(1-S_w) \quad ; \tag{47}$$

<u>Instantaneous gas oil ratio in the conformance zone:</u>

$$(R)_e = R_s + \frac{B_o K_g \mu_o}{B_g K_o \mu_g} \quad ; \tag{48}$$

Finite difference material balance:

$$\Delta_i^{i+1}N = \frac{(1-N_p^i)\Delta_i^{i+1}(\frac{B_o}{B_g}-R_s)-B_o^o\Delta_i^{i+1}(\frac{1}{B_g})}{(\frac{B_o}{B_g}-R_s)^{i+1}+R_{pav}(1-I)}$$

$$= (1-e)\Delta N^p+\Delta N^e \quad . \qquad (49)$$

Since the conformance factor, e, assumes major emphasis in this portion of the solution, its determination by one of the available procedures is assumed as an extraneous requiremant to the main line program and is considered as input data.

The main line program is composed of three computational parts:

1. Primary depletion drive calculation and well production rate calculation is performed.
2. When field pressure has declined to some arbitrary pressure (in our case 900 psia.), 60% of the current volume of produced gas is assumed reinjected into the reservoir.
3. The conformance factor is then reinitialized (in the example, e = 0.5) for field pressures declining to 900 psia with this 60% volume of gas reinjected.

The calculation procedure for the example used and suggested for subsequent use of this program was as follows:

a. Initial conditions, $N_p = 0$, were assumed.

b. Pressure was assumed reduced to P_2.

c. Cumulative oil production was estimated as N_p^2, with incremental production $N_p' = N_p^2 - N_p^1$.

d. S_o^2 and N_p'' were evaluated where N_p'' represented the calculated oil incremental production.

e. N_p' and N_p'' were compared, and, if not equal, or the difference was not less than 1%, then a new estimate of N_p^2 was made and the iteration repeated until the desired accuracy was obtained.

f. New cumulative oil production would be $(N_p^{i-1} + N_p'')$. The procedure is repeated through n pressure steps until abondonment pressure is reached.

The flow chart for the general finite difference material balance on a depletion-drive reservoir is given on the following pages. The program, suitable for similar finite difference solutions on hydrocarbon systems which satisfy the constraints and assumptions imposed is in the appendix. The example of Pirson's was used for checking the program and its validity. As in the previous techniques, the program's accuracy is deemed superior to that of the example problem.

Figure 4

Flow Chart of The Finite Difference Material Balance

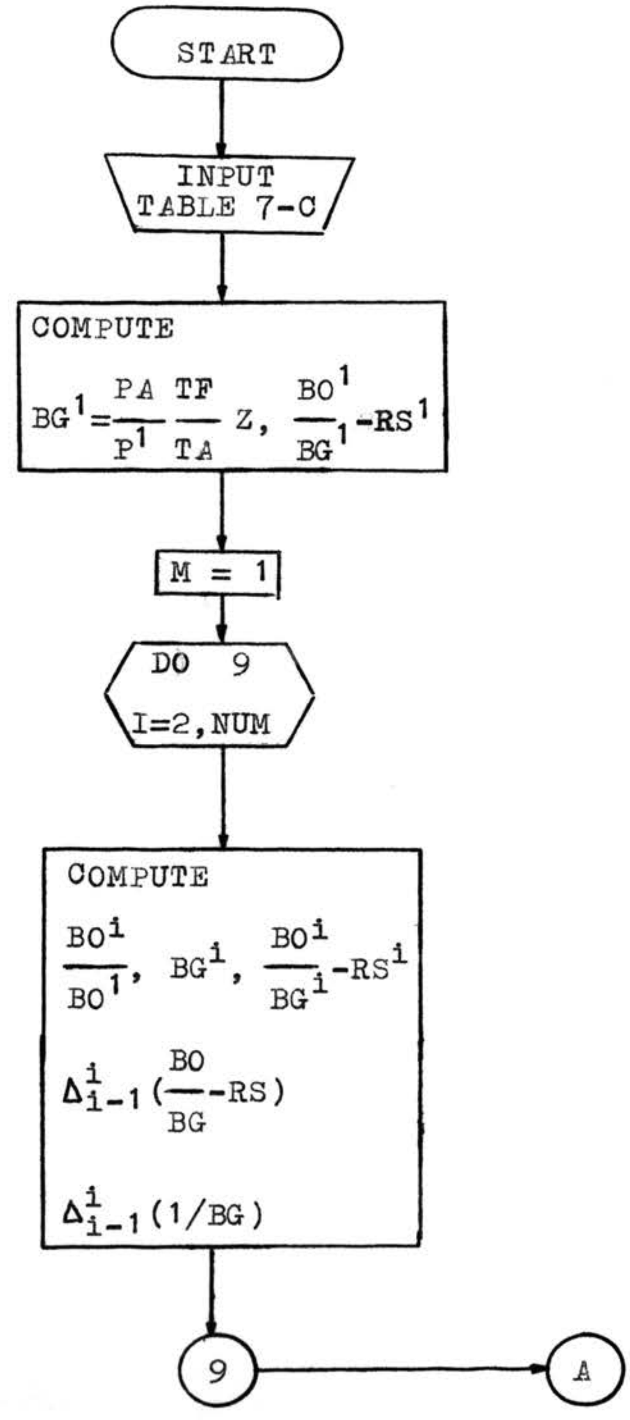

Figure 4

(continued)

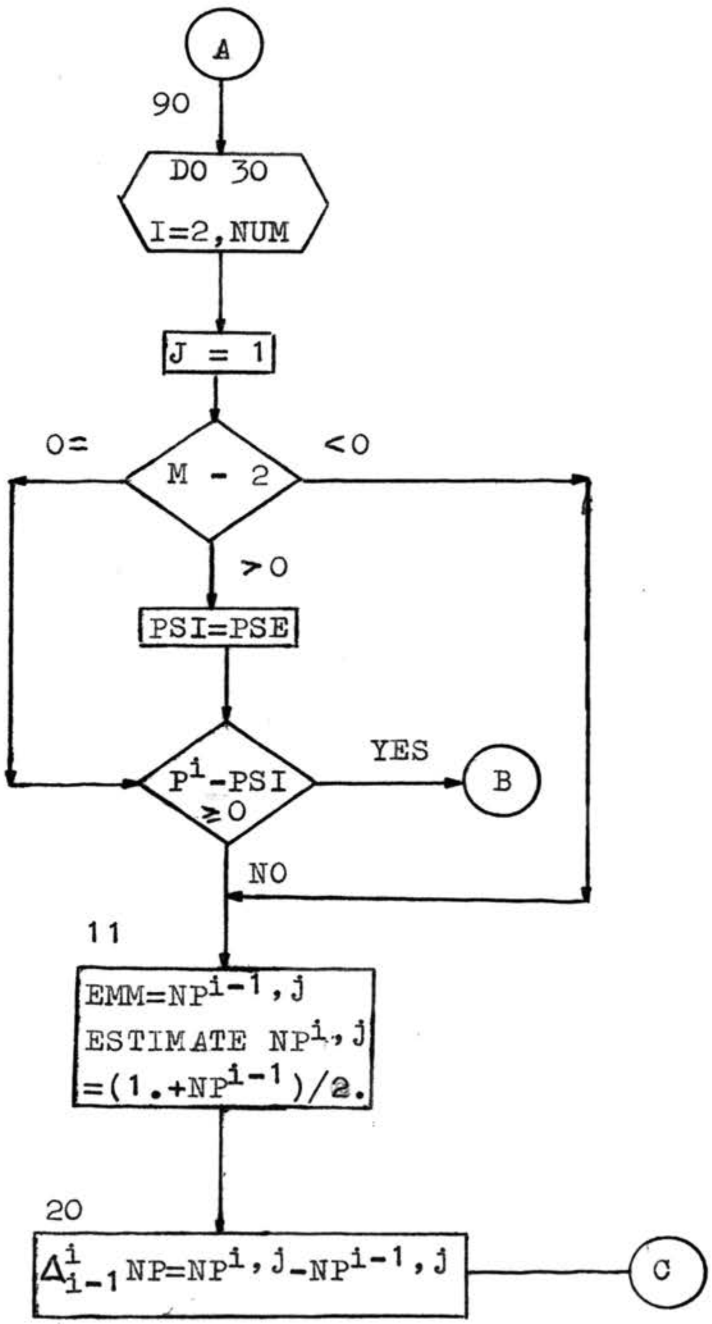

Figure 4

(continued)

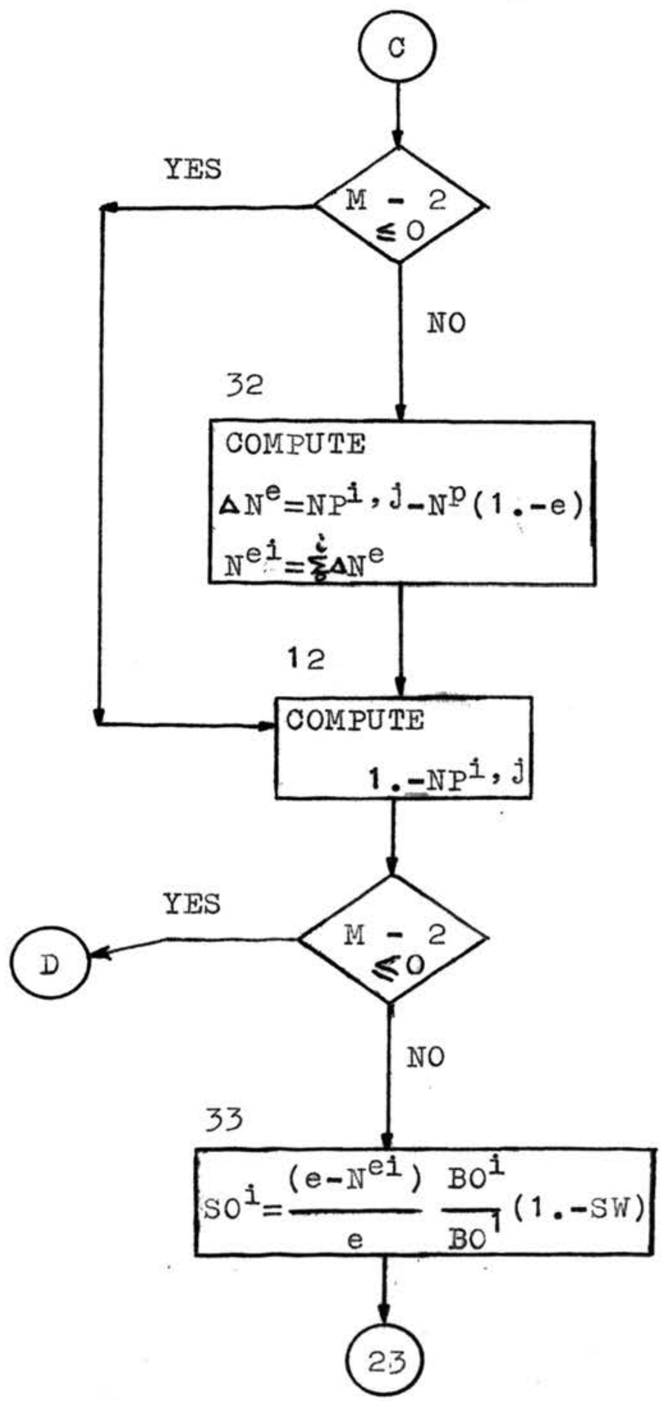

Figure 4

(continued)

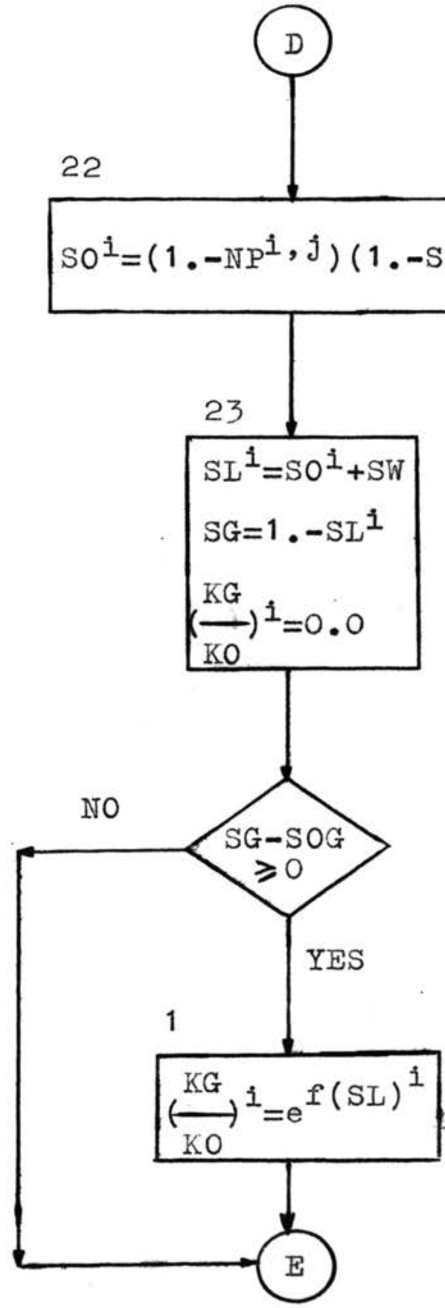

Figure 4

(continued)

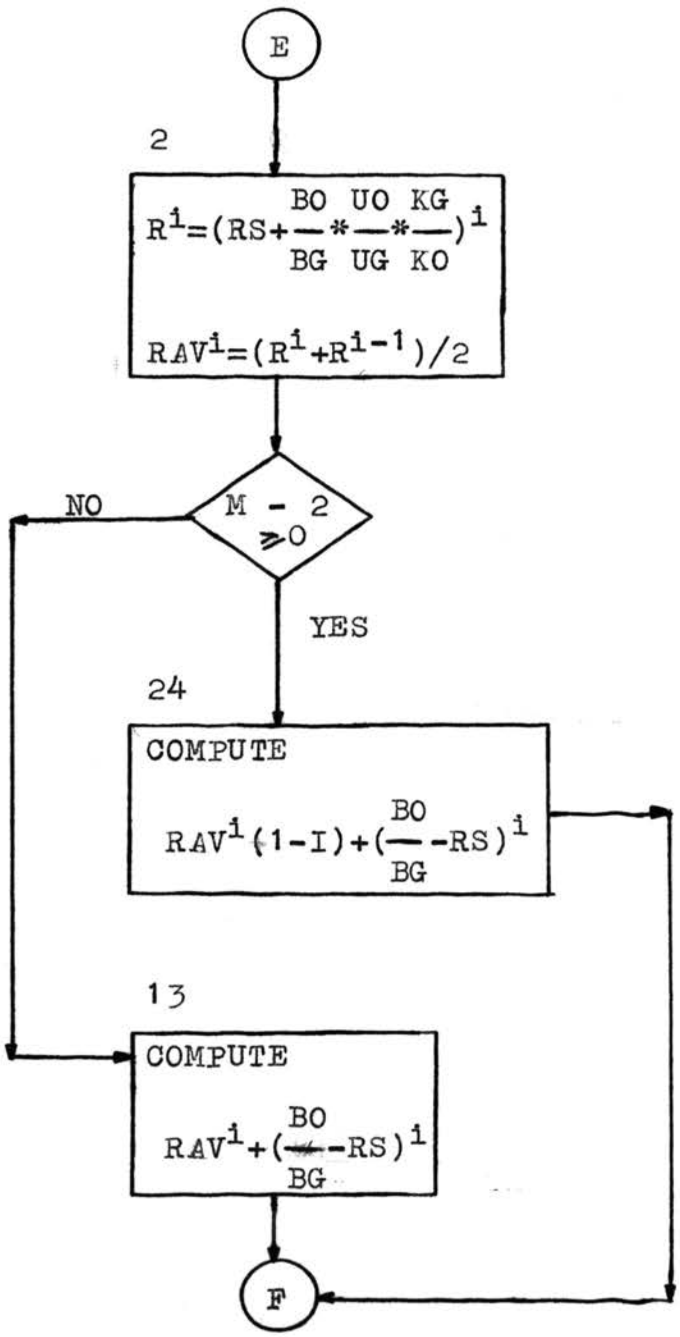

Figure 4

(continued)

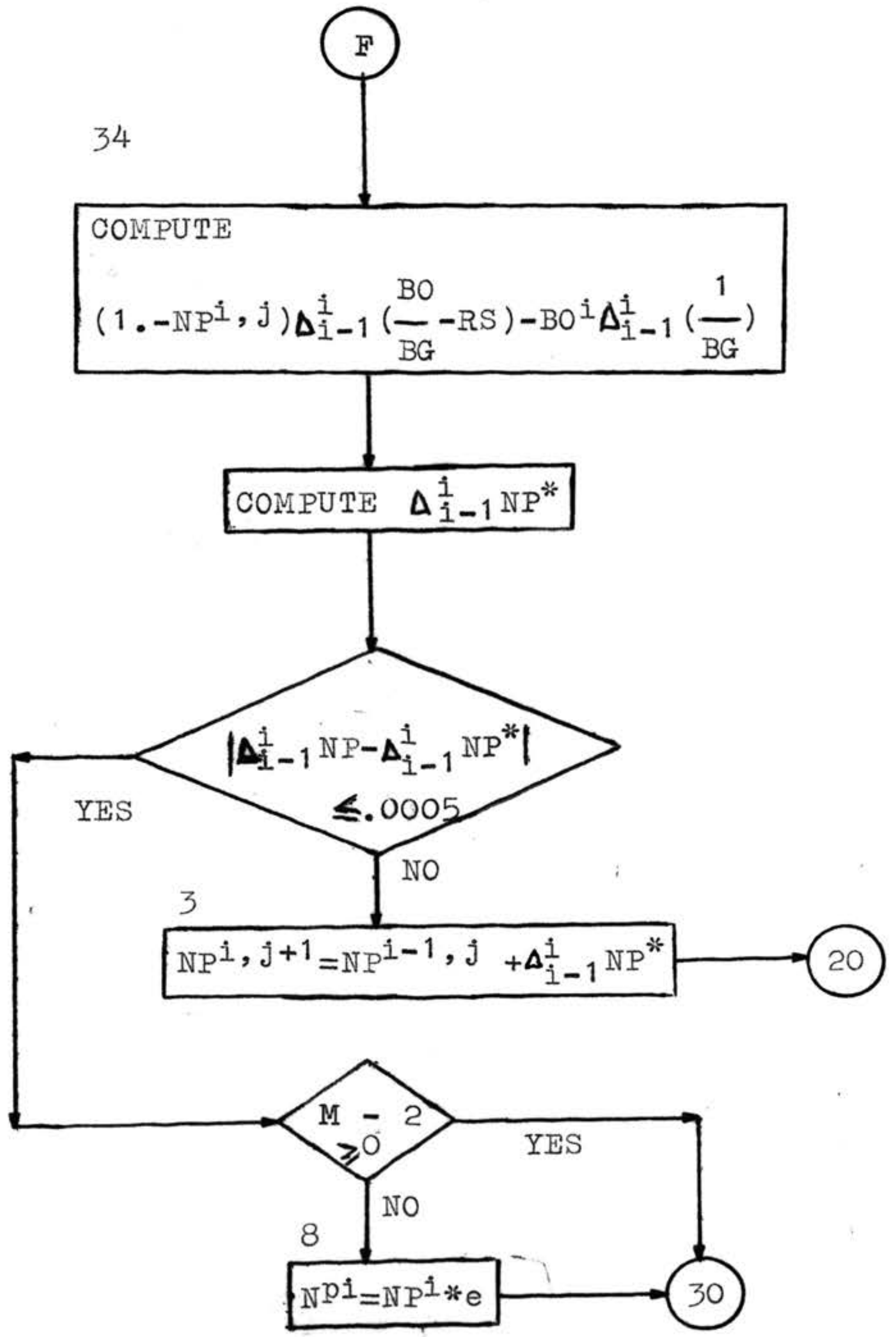

Figure 4

(continued)

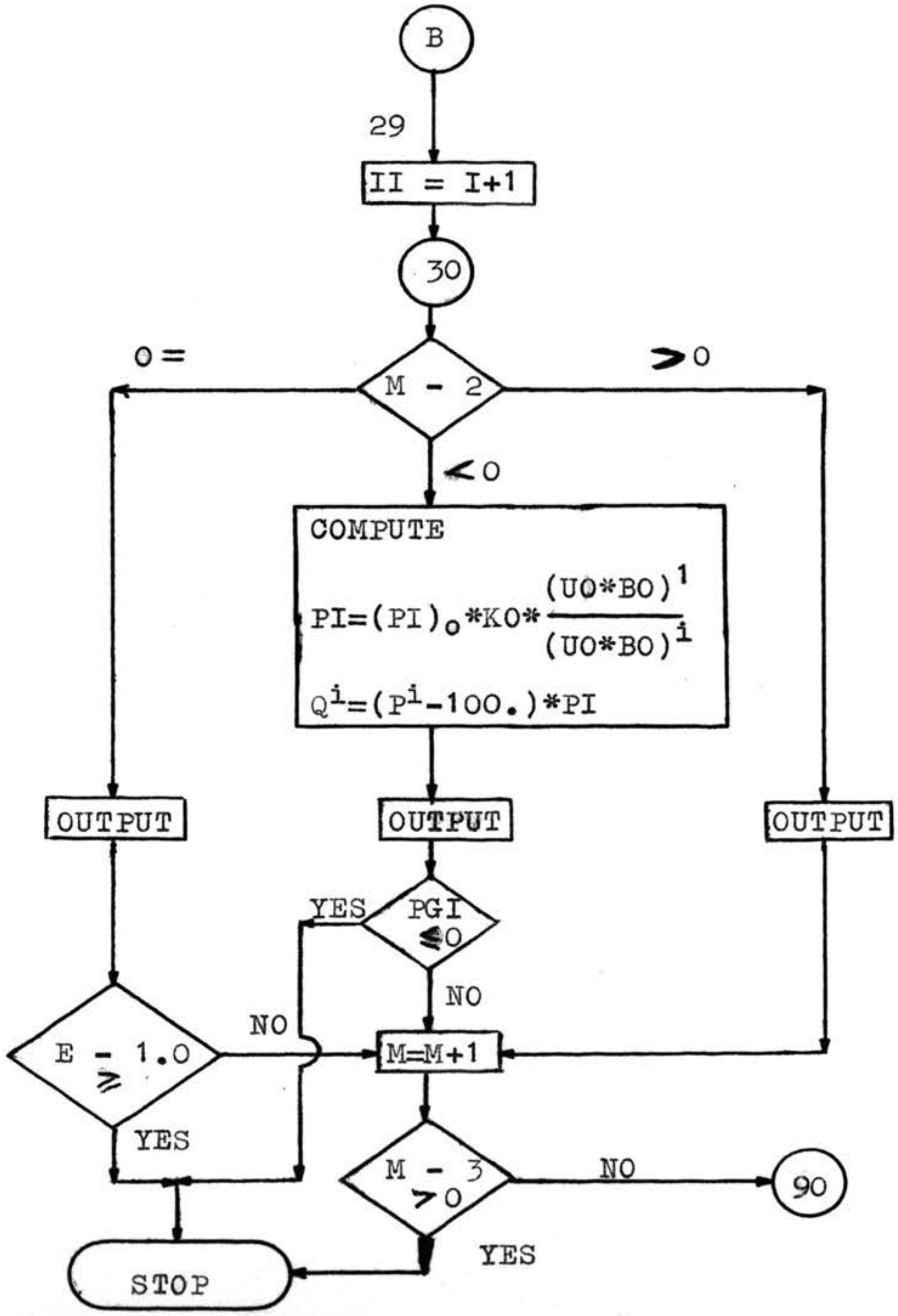

TABLE 3

Depletion drive calculation by the finite difference material balance

Pressure	ΔN_p		N_p		$1 - N_p$		B_o/B_o^o	
	Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
1400	.018	.0200	.018	.0200	.9820	.9800	.990	.9903
1300	.0246	.0240	.0426	.0441	.9574	.9559	.982	.9807
1200	.0309	.0293	.0735	.0734	.9265	.9266	.972	.9710
1100	.0359	.0335	.1094	.1068	.8916	.8932	.962	.9605
1000	.0290	.0293	.1384	.1362	.8616	.8638	.952	.9508
900	.0230	.0240	.1614	.1602	.8386	.8398	.942	.9412
800	.0184	.0203	.1808	.1805	.8192	.8195	.932	.9307
700	.0125	.0120	.1933	.1925	.8067	.8075	.921	.9291
600	.0104	.0096	.2037	.2021	.7963	.7975	.913	.9114
500	.0092	.0086	.2139	.2106	.7861	.7894	.902	.9009
400	.0077	.0075	.2206	.2182	.7794	.7818	.890	.8912
300	.0077	.0073	.2288	.2254	.7717	.7746	.881	.8807
200	.0081	.0075	.2369	.2329	.7631	.7671	.867	.8678
100	.0103	.0090	.2471	.2419	.7529	.7581	.850	.8509
14.7	.0233	.0224	.2704	.2643	.7296	.7357	.805	.8058

TABLE 3 (continued)

S_o		S_L		K_g/K_o		R_p	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
.776	.7764	.976	.9764	0	0	82.8	82.8
.743	.7500	.943	.9500	0	0	78.4	78.4
.721	.7198	.921	.9198	0	0	74.1	74.1
.685	.6863	.885	.8863	.0029	.0026	97.7	95.0133
.655	.6571	.855	.8571	.011	.0096	163.8	152.7943
.631	.6323	.831	.8323	.025	.0243	268.2	264.3540
.610	.6102	.810	.8102	.046	.0486	411.1	419.0571
.595	.6002	.795	.8002	.067	.0642	526.5	512.3042
.581	.5818	.781	.7818	.093	.1020	676.0	717.2148
.568	.5689	.768	.7689	.13	.1365	816.2	862.1733
.554	.5574	.754	.7574	.17	.1736	942.4	968.7012
.544	.5458	.744	.7458	.20	.2185	952.0	1051.3096
.529	.5326	.729	.7326	.27	.2791	1004.9	1062.3926
.512	.5161	.712	.7161	.36	.3732	764.7	883.6497
.470	.4743	.670	.6743	.84	.7573	365.5	328.9297

TABLE 3 (continued)

R_{pav}		$\frac{B_o}{B_g}-R_s$		$R_{pav}+(\frac{B_o}{B_g}-R_s)$		$\Delta(\frac{B_o}{B_g}-R_s)$	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
85.1	85.1000	69.2	70.1515	154.3	155.2525	-11.2	-10.0289
80.6	80.6000	58.8	59.7352	139.4	140.3352	-10.4	-10.4163
71.3	76.2500	48.8	50.4461	120.1	126.6961	-10.0	-9.2891
85.9	84.5567	39.8	41.4333	125.7	125.9900	-9.0	-9.0128
130.8	123.9038	31.1	32.3296	161.9	156.2334	-8.7	-9.1038
216.0	208.5741	23.4	24.4425	239.4	233.0166	-7.7	-7.8871
339.7	341.7056	17.3	15.2623	357.0	356.9678	-6.1	-9.1802
468.8	465.6807	10.8	11.6284	479.6	477.3091	-6.5	-3.6338
601.3	614.7595	5.1	5.2848	606.4	620.0442	-5.7	-6.3436
746.3	789.6941	.3	.6591	746.4	790.3530	-4.8	-4.6258
879.3	915.4373	-3.7	-3.4998	875.6	911.9373	-4.0	-4.1589
947.0	1010.0054	-6.6	-6.3325	940.4	1003.6729	-2.9	-2.8327
978.5	1056.8511	-8.2	-7.9179	970.3	1048.9331	-1.6	-1.5854
884.8	973.0210	-8.5	-7.7968	876.3	965.2241	-0.3	.1212
565.1	606.2896	.94	.9369	566.0	607.2263	9.44	8.7337

TABLE 3 (continued)

$(1-N_p)^{i-1}\Delta(\frac{B_o}{B_g}-R_s)$		$(\frac{1}{B_g})$		$B_o^o\Delta(\frac{1}{B_g})$		$(1-N_p)^{i-1}\Delta(\frac{B_o}{B_g}-R_s)-B_o^o\Delta(\frac{1}{B_g})$	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
-11.2	-10.0289	-11.25	-10.5846	-13.98	-13.1354	2.78	3.1066
-10.2	-10.2078	-11.00	-10.9473	-13.64	-13.5856	3.44	3.3778
-9.57	-8.8798	-10.70	-10.1470	-13.28	-12.5924	3.7	3.7127
-8.33	-8.3515	-10.35	-10.1250	-12.85	-12.5652	4.52	4.2135
-7.75	-8.1311	-10.00	-10.2415	-12.41	-12.7096	4.66	4.5785
-6.63	-6.8132	-9.75	-10.0096	-12.11	-12.4219	5.48	5.6088
-5.11	-7.7095	-9.40	-12.0619	-11.69	-14.9688	6.58	7.2593
-5.32	-2.9779	-9.10	-7.0355	-11.30	-8.7311	5.98	5.7532
-4.60	-5.1224	-8.75	-8.8932	-10.88	-11.0364	6.28	5.9140
-3.82	-3.6910	-8.60	-8.8932	-10.69	-10.4795	6.87	6.7885
-3.15	-3.2828	-8.05	-8.1558	-9.99	-10.1214	6.84	6.8385
-2.26	-2.2147	-7.70	-7.6520	-9.55	-9.4961	7.29	7.2814
-1.23	-1.2281	-7.30	-7.2921	-9.06	-9.0495	7.83	7.8214
-0.23	.0929	-7.30	-6.9095	-9.06	-8.5747	8.83	8.6677
7.10	6.6213	-4.91	-5.6002	-6.10	-6.9499	13.20	13.5711

TABLE 3 (continued)

N_p

Pirson	Program
.018	.0200
.0246	.0241
.0309	.0293
.0359	.0334
.0288	.0293
.0230	.0241
.0184	.0203
.0125	.0121
.0104	.0095
.0092	.0086
.0077	.0075
.0077	.0073
.0081	.0075
.0102	.0090
.0233	.0223

TABLE 4

Tabulation for PI and well-production rate calculation

Pressure	S_L		K_o		U_o		B_o	
	Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
1500	1.000	1.0000	1.000	1.0000	1.21	1.2100	1.241	1.241
1300	.949	.9500	.775	.7750	1.25	1.2500	1.217	1.217
1100	.888	.8863	.575	.5750	1.30	1.3000	1.192	1.192
900	.836	.8323	.457	.4570	1.37	1.3700	1.168	1.168
700	.799	.8002	.386	.3860	1.51	1.5100	1.143	1.143
500	.768	.7458	.338	.3380	1.77	1.7700	1.118	1.118
300	.746	.7458	.305	.3050	2.27	2.2700	1.093	1.093
100	.714	.7161	.266	.2660	3.37	3.3700	1.056	1.056

TABLE 4 (continued)

$\mu_o B_o$		$(\mu_o B_o)^o K_o$		$\dfrac{(\mu_o B_o)^o K_o}{\mu_o B_o}$		PI		N_p	
Pirson	**Program**	**Pirson**	**Program**	**Pirson**	**Program**	**Pirson**	**Program**	**Pirson**	**Program**
1.5016	1.5016	1.5016	1.5016	1.000	1.0000	.500	.5000	0	0
1.5213	1.5212	1.1637	1.1637	.765	.7650	.384	.3825	.045	.0441
1.5496	1.5496	.8634	.8634	.557	.5572	.279	.2786	.105	.1068
1.6002	1.6002	.6862	.6862	.429	.4289	.215	.2144	.155	.1602
1.7259	1.7410	.5796	.5796	.336	.3329	.168	.1665	.187	.1925
1.9789	1.9789	.5075	.5075	.256	.2565	.128	.1282	.212	.2106
2.4811	2.4811	.4580	.4580	.185	.1846	.093	.0923	.225	.2254
3.5587	3.5587	.3994	.3994	.112	.1122	.056	.0561	.245	.2419

Q	
Pirson	**Program**
700	700
460	458.9961
279	278.5962
172	171.5416
101	99.8755
51	51.2966
19	18.4591
0	0

TABLE 5

Depletion - drive calculations by the finite difference material balance with dispersed gas injection, I = 0.6

Pressure	ΔN_p		$N_p=\Sigma\Delta N_p$		$1 - N_p$		Bo/B_o^1	
	Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
800	.0377	.0391	.1991	.1993	.8009	.8007	.932	.9307
700	.0249	.0199	.2240	.2192	.7760	.7808	.921	.9291
600	.0155	.0152	.2395	.2344	.7605	.7656	.913	.9114
500	.0139	.0132	.2534	.2475	.7466	.7525	.902	.9009
400	.0118	.0113	.2652	.2588	.7348	.7412	.890	.8912
300	.0110	.0108	.2762	.2696	.7238	.7304	.881	.8807
200	.0110	.0108	.2872	.2804	.7128	.7196	.867	.8678
100	.0132	.0127	.3004	.2931	.6996	.7069	.850	.8509
14.7	.0306	.0293	.3310	.3225	.6690	.6775	.805	.8058

TABLE 5 (continued)

S_o		S_L		K_g/K_o		R_p	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
.598	.5962	.798	.7962	.06	.0712	519.8	589.2722
.571	.5803	.771	.7803	.12	.1054	903.5	810.3665
.555	.5582	.755	.7582	.17	.1709	1163.6	1172.2505
.539	.5423	.739	.7423	.22	.2337	1352.5	1447.1770
.522	.5284	.722	.7284	.30	.3015	1636.9	1653.8879
.509	.5146	.709	.7146	.38	.3834	1783.0	1820.9658
.494	.4996	.694	.6996	.50	.4945	1842.0	1862.6050
.475	.4812	.675	.6812	.74	.6742	1554.7	1582.1028
.430	.4368	.630	.6368	1.18	1.5053	513.0	653.0085

R_{pav}		$R_{pav}(1-I)$		B_o/B_g-R_s		$B_o/B_g-R_s+R_{pav}(1-I)$	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
394.0	426.8130	157.5	170.7252	17.3	15.2623	157.5	185.9875
585.9	699.8193	234.2	279.9277	10.8	11.6284	245.0	291.5562
1033.6	991.3083	413.0	396.5232	5.1	5.2848	418.1	401.8079
1257.9	1309.7136	503.0	523.8853	.3	.6591	503.3	524.5442
1494.6	1550.5325	598.0	624.2129	-3.7	-3.4998	594.4	616.7129
1710.0	1737.4268	684.0	694.9707	-6.6	-6.3325	677.4	688.6382
1812.7	1841.7854	725.0	736.7141	-8.2	-7.9179	716.8	728.7961
1698.7	1722.3538	679.0	688.9414	-8.5	-7.7968	670.5	681.1445
1033.9	1117.5557	414.0	447.0222	.94	.9369	414.9	447.9590

TABLE 5 (continued)

$\Delta(B_o/B_g-R_s)$		$(1-N_p)\Delta(B_o/B_g-R_s)$		$\Delta(1/B_g)$		$B_o^o\Delta(1/B_g)$	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
-6.1	-9.1802	-5.11	-7.7095	-9.40	-12.0619	-11.69	-14.9688
-6.5	-3.6338	-5.21	-2.9097	-9.10	-7.0335	-11.31	-8.7311
-5.7	-6.3436	-4.42	-4.9531	-8.75	-8.8932	-10.88	-11.0364
-4.8	-4.6258	-3.65	-3.5417	-8.60	-8.4444	-10.69	-10.4795
-4.0	-4.1589	-2.98	-3.1294	-8.05	-8.1558	-9.99	-10.1214
-2.9	-2.8327	-2.13	-2.0995	-7.70	-7.6520	-9.55	-9.4961
-1.6	-1.5854	-1.16	-1.1580	-7.30	-7.2921	-9.06	-9.0495
-0.3	0.1212	-0.21	0.0872	-7.30	-6.9095	-9.06	-8.5747
9.44	8.7337	6.60	6.1736	-4.91	-5.6002	-6.10	-6.9499

$(1-N_p)\Delta(B_o/B_g-R_s)$ $-B_o^o\Delta(1/B_g)$		N_p	
Pirson	Program	Pirson	Program
6.58	7.2593	.0377	.0390
6.10	5.8214	.0249	.0200
6.46	6.0833	.0155	.0151
7.04	6.9378	.0139	.0132
7.01	6.9920	.0118	.0113
7.42	7.3966	.0110	.0107
7.90	7.8915	.0110	.0108
8.85	8.6619	.0132	.0127
12.70	13.1235	.0306	.0293

TABLE 6

Depletion-drive calculation by finite difference material balance with dispersed gas injected (I = 0.6) and conformance factor (e = 0.5)

Pressure	$\Delta N_p = \Delta N^p(1-e) + N^e$		ΔN^p		$\Delta N^p(1-e)$		ΔN^e	
	Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
800	.03310	.0348	.0190	.0203	.0095	.0101	.0236	.0246
700	.01765	.0167	.0127	.0120	.00625	.0060	.0113	.0107
600	.01392	.0126	.0105	.0096	.0051	.0048	.0089	.0078
500	.0125	.0111	.0092	.0086	.0046	.0043	.0079	.0068
400	.0103	.0096	.0080	.0075	.0040	.0038	.0063	.0059
300	.00965	.0091	.0075	.0073	.00375	.0036	.0059	.0055
200	.0096	.0092	.0082	.0075	.0041	.0037	.0055	.0055
100	.01135	.0109	.0098	.0090	.00495	.0045	.0064	.0064
14.7	.0244	.0253	.0248	.0224	.0214	.0112	.0120	.0141

TABLE 6 (continued)

$N_e=\Sigma\Delta N_e$		$N_p=\Sigma\Delta N_p$		$1-N_p$		S_o		S_L	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
.1045	.1047	.1945	.1950	.8055	.8050	.5896	.5886	.7896	.7886
.1153	.1154	.21215	.2117	.78785	.7883	.5668	.5717	.7668	.7717
.1242	.1232	.22607	.2243	.77393	.7757	.549	.5494	.749	.7494
.1321	.1301	.23857	.2354	.76143	.7646	.5319	.5332	.7319	.7332
.1384	.1359	.24887	.2450	.75113	.7550	.5149	.5191	.7149	.7191
.1454	.1414	.25858	.2541	.74142	.7459	.501	.5053	.701	.7053
.1499	.1469	.26808	.2633	.73192	.7367	.485	.4903	.685	.6903
.1563	.1533	.27945	.2742	.72055	.7258	.4675	.4721	.6675	.6721
.1683	.1674	.30385	.2996	.69615	.7004	.4275	.4288	.6275	.6288

$(K_g/K_o)_e$		R_{pe}		R_{peav}		$R_{peav}(1-I)$	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
.0762	.0862	645.1	702.5195	448	483.4368	179.2	193.3747
.133	.1283	995.5	1975.7578	820	839.1387	328.1	335.6553
.185	.2039	1271	1389.4434	1128	1182.6006	451.2	473.0400
.251	.2767	1540.2	1704.6396	1405	1547.0415	520.0	618.8167
.338	.3548	1840.9	1941.3994	1691	1823.0195	676.6	729.2078
.430	.4496	2010.0	2129.3355	1928	2035.3665	770.0	814.1465
.590	.5789	2172.4	2174.0144	2091.2	2151.6738	836.5	860.6694
.840	.7894	1765.7	1846.8164	1968	2010.4153	787.4	804.1660
2.050	1.7708	891.0	767.4971	1328	1307.1567	31.	522.8625

TABLE 6 (continued)

B_o/B_g-R_s		$R_{peav}(1-I)+(B_o/B_g-R_s)$		$\Delta(B_o/B_g-R_s)$		$(1-N_p)\Delta(B_o/B_g-R_s)$	
Pirson	Program	Pirson	Program	Pirson	Program	Pirson	Program
17.3	15.2623	196.5	208.6370	-6.1	-9.1802	-5.12	-7.7095
10.8	11.6284	339.0	347.2837	-6.5	-3.6338	-5.24	-2.9254
5.1	5.2848	456.0	478.3247	-5.7	-6.3436	-4.48	-5.0009
.3	.6591	562.5	619.4756	-4.8	-4.6258	-3.71	-3.5883
-3.7	-3.4998	673.3	725.7078	-4.0	-4.1587	-3.05	-3.1799
-6.6	-6.3325	764.6	807.8140	-2.9	-2.8327	-2.18	-2.1386
-8.2	-7.9179	828.3	852.7515	-1.6	-1.5854	-1.19	-1.1825
-8.5	-7.7968	779.0	796.3691	-0.3	0.1212	-0.22	0.0893
.94	.9369	532.0	523.7993	9.44	8.7337	6.80	6.3388

$B_o^o\Delta(1/B_g)$		$(1-N_p)\Delta(B_o/B_g-R_s)$ $-B_o^o\Delta(1/B_g)$		N_p	
Pirson	Program	Pirson	Program	Pirson	Program
-11.69	-14.9688	6.57	7.2593	.0334	.0348
-11.31	-8.7311	6.07	5.8057	.0179	.0167
-10.88	-11.0364	6.36	6.0355	.0140	.0126
-10.69	-10.4795	6.98	6.8912	.01238	.0111
-9.99	-10.1214	6.94	6.9415	.0103	.0096
-9.55	-9.4961	7.39	7.3574	.00965	.0091
-9.06	-9.0495	7.87	7.8670	.0095	.0092
-9.06	-8.5747	8.84	8.6646	.01135	.0109
-6.10	-6.9499	12.90	13.2887	.0242	.0254

V. DATA REQUIRED FOR MATERIAL BALANCE SOLUTION

In the performance calculations of depletion drive systems, considerable input data are required which must be stored in the computer prior to the precessing of the calculations. The basic data required are: (a) the numbers of depletion stages, (b) the pressures of each stage, (c) gas solubility, (d) oil and gas formation volume factors, (e) oil viscosity, (f) ratio of oil and gas viscosity, (g) coefficients of $K_g/K_o = e^{f(S_L)}$, (h) water saturation, and (if any), (i) fraction of produced gas injection, (j) ratio of initial reservoir gas volume to initial reservoir oil volume, (k) water encroachment, (l) water production, and/or (m) the conformance factor.

The coefficients of $K_g/K_o = e^{f(S_L)}$ were calculated by a least square fit resulting in a polynomial approximation with errors less than 1% between approximated and observed values, (Figure 1).

All data presented in Table 7 and Table 8 pertain to the illustrative example previously mentioned. These data for the illustrative example were taken from Pirson (8).

The following formats were used in those programs for the input data, which are shown in Table 7-A, 7-B, and 7-C.

a. Tarner's depletion drive calculation,

100 FØRMAT (I5,5F10.4): card 1

101 FØRMAT (F10.3,F6.1,F10.4,E15.3,F9.2,F10.3): cards 2-16

102 FORMAT (4E18.8): card 17

b. Schilthuis equation,

103 FØRMAT (7F10.5): card 1 and 19

100 FØRMAT (I5): card 2

101 FØRAMT (F10.3,F6.1,F10.4,E15.3,F9.2,F10.3): cards 3-17

102 FØRMAT (4E18.8): card 18

c. Finite differences material balance,

100 FØRMAT (I5,5F10.5): card 1 and 19

101 FØRMAT (6F10.4): cards 2-17 and 20-21

102 FØRMAT (4E18.8): card 18

The data in Table 8-A and 8-B were used directly in depletion drive programs with the exception of the description of $K_g/K_o = e^{f(SL)}$, in which case the least square fit was used to find the coefficient of that equation for use within the main line program.

TABLE 7-A

Input data of Tarner's method

		number of stages NUM	the oil saturation below this value the K_g/K_o other than zero SGO	water saturation SW
card	1	15	0.897	0.0

		pressure of each stages PSIA	solubility RS	oil formation volume factor BO	gas formation volume factor BG	viscosity ratio of oil and gas RUOG	viscosity of oil UO
card	2	2000.	88.	1.269	.610E-02	46.	.890
	3	1850.	83.	1.254	.665E-02	49.	.980
	4	1700.	78.	1.239	.730E-02	53.	1.03
	5	1550.	73.	1.224	.815E-02	57.	1.10
	6	1400.	68.	1.209	.910E-02	62.	1.18
	7	1250.	63.	1.194	.103E-01	67.	1.27
	8	1100.	58.	1.179	.119E-01	72.	1.33
	9	950.	53.	1.164	.140E-01	77.5	1.42
	10	800.	48.	1.149	.170E-01	84.	1.51
	11	650.	43.	1.134	.210E-01	91.5	1.60
	12	500.	38.	1.119	.280E-01	100.	1.70
	13	350.	32.	1.110	.410E-01	111.	1.83
	14	200.	24.	1.075	.730E-01	125.	2.06
	15	100.	16.	1.052	.148E-00	145.	2.32
	16	14.4	0.	1.017	.115E+01	188.	3.00

Coefficients of function $K_g/K_o = e^{(A(1)+A(2)*S_o+A(3)*S_o^2)}$

		A(1)	A(2)	A(3)
card	17	.12845010E+02	-.22829311E+02	.90475397E+00

TABLE 7-B

Input data of Schilthuis equation

		fraction of produced gas injection, PGI	presence of gas cap, GC	fraction of produced gas injected back into gas cap, GCI	water encroachment during an interval, WE	water produced during an interval, WP
card	1	0.0	0.0	0.0	0.0	0.0
	1a*	0.4	0.0	0.0	0.0	0.0
	1b*	0.0	0.5	0.0	0.0	0.0
	1c*	0.0	0.5	0.04	0.0	0.0
	1d*	0.0	0.5	0.04	0.4	0.2

		number of stages NUM
card	2	15

cards 3 - 18 same as table 7-A cards 2 - 16

		the highest oil saturation that $K_g/K_o=0$ SGO	water saturation SW
card	19	0.897	0.0

* 1a, 1b, 1c and 1d are four modifications. If any one of these four is going to be calculated card 1 must be replaced by the corresponding card.

TABLE 7-C

Input data of Finite Difference Material Balance

		number of stages, NUM	the gas saturation below this Kg/Ko other than zero, SOG	formation temperature, TF	atmosphere temperature, TA	atmosphere pressure, PA	water saturation SW
card	1	16	0.1	555.	520.	14.7	0.2

		pressure PSIA	oil formation volume factor BO	gas solubility RS	compressibility Z	oil viscosity UO	gas viscosity UG
card	2	1500.	1.241	87.4	.708	1.21	.0160
	3	1400.	1.229	82.8	.717	1.23	.0158
	4	1300.	1.217	78.4	.730	1.25	.0154
	5	1200.	1.205	74.1	.740	1.27	.0150
	6	1100.	1.192	69.7	.752	1.30	.0147
	7	1000.	1.180	65.6	.768	1.33	.0144
	8	900.	1.168	60.8	.786	1.37	.0139
	9	800.	1.155	55.1	.807	1.43	.0134
	10	700.	1.143	50.5	.828	1.51	.0130
	11	600.	1.131	45.6	.850	1.62	.0125
	12	500.	1.118	40.2	.872	1.77	.0120
	13	400.	1.106	34.9	.898	1.97	.0115
	14	300.	1.093	29.0	.922	2.27	.0110
	15	200.	1.077	22.4	.948	2.70	.0105
	16	100.	1.056	14.7	.975	3.37	.0100
	17	14.7	1.000	0.0	1.000	4.40	.0095

TABLE 7-C
(continued)

coefficient of function K_g/K_o

		A(1)	A(2)	A(3)
card	18	.11177865E+03	-.45190209E+03	.62646718E+03
		A(4)		
		-.30066386E+03		

		number of production rate calculations, L	original production index, PIO	pressure starting gas injection, PSI	pressure at which consider conformance factor, PSE	dispersed gas injection, PGI	conformance factor, E
card	19	9	0.50	900.	900.	0.6	0.5

oil relative permeability, PKO

card	20	1.000	.949	.888	.836	.799	.768
	21	.746	.714	.671			

TABLE 8-A

Basic data of Tarner's and Schilthuis method; K_g/K_o relation at irreducible oil saturation

S_o	K_g/K_o	S_o	K_g/K_o
100. %	0.0	76. %	0.0185
98. %	0.0	74. %	0.0285
96. %	0.0	72. %	0.044
94. %	0.0	70. %	0.068
92. %	0.0	68. %	0.104
89.7 %	0.0	66. %	0.161
88. %	0.00144	64. %	0.250
86. %	0.00220	62. %	0.385
84. %	0.00338	60. %	0.590
82. %	0.00518	58. %	0.915
80. %	0.00795	56. %	1.40
78. %	0.0120	54. %	2.18

Water saturation = 0.0

TABLE 8-B

Basic data of finite difference K_g/K_o relation at irreducible water saturation:

S_L	K_g/K_o	S_L	K_g/K_o
90.	0.001	70.	0.45
87.5	0.005	67.5	0.73
85.	0.0135	65.	1.20
82.4	0.03	52.5	2.00
80.	0.06	60.	3.40
77.5	0.11	57.5	6.30
75.	0.18	55.	14.00
72.5	0.28		

Water saturation = 0.20

VI. DISCUSSION

The concepts of three established techniques for the prediction of oil production in a depletion drive reservoir have been programmed using 40 K or larger compilers. Because of the data and examples used, the programs develop and output much more than is commonly desired in such calculations. It is believed that one third of the output could be reduced if only the final results are desired. For example: In Tarner's method, the following statements can be condensed if columns (4), (6), (7), (8), (9), and (12) are not desired as output:

```
   DBO(I)=BO(1)-BO(I)  -------------------- column  (4)
   DBOG(I)=DBO(I)/BG(I)  ------------------ column  (6)
   DNSB(I)=RS(I-1)-RS(I)+DBOG(I-1)-DBOG(I) - column (7)
   RBOG(I)=BO(I)/BG(I)  ------------------- column  (8)
   DBOGS(I)=RBOG(I)-RS(I)  ---------------- column  (9)
   J=1
   EMM=0.0
   EM=1.0
   EN(I.J)=(1.+EMM)/2.  ------------------- column (10)
20 DNP(I)=EN(I,J)-ENU(I-1)  --------------- column (11)
   CNBOS(I)=EN(I,J)*DBOGS(I)  ------------- column (12)
   DG(I)=DNSB(I)+CNBOS(I-1)-CNBOS(I)  ----- column (13)
```

reducing to

```
      J=1
      EMM=0.0
      EM=1.0
      EN(I,J)=(1.+EMM)/2. --------------------- column  (10)
   20 DNP(I)=EN(I,J)-ENU(I-1)  ----------------- column  (11)
      DG(I)=RS(I-1)-RS(I)-(BO(1)-BO(I))/BG(I)
           +(BO(1)-BO(I-1))/BG(I-1)-EN(I,J)*
           (BO(I)/BG(I)-RS(I))+ENU(I-1)*
           (BO(I-1)/BG(I-1)-RS(I-1))  --------- column  (12)
```

In the above example, the statements have been reduced by a factor of two and at least 240 bytes of core storage have been eliminated. This is true in the other two program also.

The depletion drive technique has been solved by trial-and-error procedures based on input limits on accuracy. These three programs were each started at a produced oil value of N_p = 0.5. However, since it was assumed that N = 1, any arbitrary value between 0 and 1 can be picked as a starting point.

In Table 1 and 2, the programmed calculations and Pirson's results were very close. In Table 3, 5, and 6 the fraction of oil production in the example calculation and in Pirson's results do indicate differences. The important factor in these differences arise from the (1./BG) value. The (1./BG) value as determined by hand-calculation loses accuracy which is retained in the machine calculations. This fact indicates that there is some error in Pirson's results. Which has been minimized on the computer.

If it is possible to equate B_o, B_g, **Z**, and R_s as polynomial functions of pressure and to determine the coefficients of following relationships by a least square fit,

$$\begin{aligned} B_o &= F(P) \\ B_g &= F(P) \\ Z &= F(P) \\ R_s &= F(P) \end{aligned} \tag{50}$$

the tabulated data could be greatly reduced, programming time reduced, and accuracy of the results improved. The depletion drive program can be used to determine the cumulative production fraction at any pressure. The only input data required are the coefficients of Eq. (50).

It is recommended that the data in Table 7-A, 7-B, and 7-C are used directly when the accuracy of the least square fit on B_g exceeds 1%.

VII. CONCLUSION

Solutions of the Tarner, Schilthuis, and Finite Difference Material Balance methods for depletion drive reservoir calculations using computer techniques to study pressure - cumulative production have been presented. Machine calculations using the three methods are a definite improvement when compared to approximately 18 to 24 hours "hand" calculation time for up to 10 pressure steps.

A single program has been written for each method which will account for the various differences in application to suitable operating conditions such as presence of a gas cap, reinjection of gas into gas cap or oil zone, or water encroachment. Modification of each program can be made if conditions warrant other considerations.

VIII. BIBLIOGRAPHY

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IX. VITA

Tu Kao Chen was born on November 10, 1937 in KiangSu, China. He received his secondary education at Nan Kung High School and graduated in 1955. In 1960 he completed the studies in Mining Engineering at Cheng Kung University. After graduating he attended ROTC training and worked at the Chinese Petroleum Corp. until he came to United States.

In September, 1964, he enrolled in the graduate school at the University of Missouri at Rolla in Petroleum Engineering.

```
      AVDEV=AVDEV+ABS(DEV)/CN
   75 STD=STD+DY**2
      STD=SQRT(STD/CN)
      WRITE (3,203) STD
      WRITE (3,204) AVDEV
  204 FORMAT (6X'AVERAGE ERROR=',E18.8)
  203 FORMAT (6X'STANDARD DEVIATION=',E18.8)
      IF (AVDEV-0.01) 78,78,20
   20 CONTINUE
   78 STOP
      END
END OF COMPILATION  MAIN     SIZE OF COMMON  00000     PROGRAM  07192
/DATA
```

```
      THLD=A(I,J)
      A(I,J)=A(LHOLD,J)
   16 A(LHOLD,J)=THLD
    9 IF (A(I,I)) 2,3,2
    2 TEMP=1./A(I,I)
      IPO=I+1
      DO 4 J=IPO,L
    4 A(I,J)=A(I,J)*TEMP
      DO 11 K=1,N
      IF (I-K) 10,11,10
    3 WRITE (3,104)
  104 FORMAT (1X,'NO SOLUTION, SYSTEM IS SINGULAR')
      GO TO 20
   10 DO 13 J=IPO,L
   13 A(K,J)=A(K,J)-A(K,I)*A(I,J)
   11 CONTINUE
      GO TO (44,84),INTC
   84 WRITE (3,300)
      DO 86 I=1,M
   86 WRITE (3,102) I,A(I,N+1)
      GO TO 95
   44 MPO=M+1
      WRITE (3,300)
  300 FORMAT (1H1)
      DO 6 I=1,MPO
      IMO=I-1
    6 WRITE (3,102) IMO,A(I,N+1)
  102 FORMAT (1X,'C(',I2,')=',E18.8)
   95 WRITE (3,201)
  201 FORMAT (15X'Y',17X'Y*',17X'DY')
      GO TO (61,71),INTC
   61 AZERO=A(1,N+1)
      L=2
      GO TO 72
   71 L=1
   72 AVDEV=0.0
      STD=0.0
      CN=NUMBR
      DO 75 I=1,NUMBR
      YC(I)=AZERO
      DO 74 J=1,M
      K=J+L-1
   74 YC(I)=YC(I)+A(K,N+1)*X(I)**J
      DY=Y(I)-YC(I)
      DEV=DY/Y(I)
      WRITE (3,202) Y(I),YC(I),DY
  202 FORMAT (6X,3E18.8)
```

```
   41 DO 20 M=1,MM
      MX2=M*2
      DO 113 I=1,MX2
      P(I)=0.0
      DO 113 J=1,NUMBR
  113 P(I)=P(I)+X(J)**I*W(I)
      GO TO (42,82),INTC
   82 N=M
      DO 90 I=1,N
      DO 90 J=1,N
      K=I+J-2
   90 A(I,J)=P(K+2)
      NPO=N+1
      DO 91 I=1,N
      A(I,NPO)=0.0
      DO 91 J=1,NUMBR
   91 A(I,NPO)=A(I,NPO)+X(J)**I*W(J)*(Y(J)-AZERO)
      GO TO 43
   42 N=M+1
      DO 30 I=1,N
      DO 30 J=1,N
      K=I+J-2
      IF (K) 29,29,28
   28 A(I,J)=P(K)
      GO TO 30
   29 A(I,I)=NUMBR
   30 CONTINUE
      NPO=N+1
      A(1,NPO)=0.0
      DO 21 J=1,NUMBR
   21 A(1,NPO)=A(1,NPO)+Y(J)*W(J)
      DO 22 I=2,N
      A(I,NPO)=0.0
      L=I-1
      DO 22 J=1,NUMBR
   22 A(I,NPO)=A(I,NPO)+Y(J)*W(J)*X(J)**L
   43 L=N+1
      DO 11 I=1,N
      LHOLD=I
      HOLD=A(I,I)
      DO 5 K=I,N
      IF (ABS(A(K,I))-ABS(HOLD)) 5,5,7
    7 HOLD=A(K,I)
      LHOLD=K
    5 CONTINUE
      IF (I-LHOLD) 8,9,8
    8 DO 16 J=1,L
```

D. Least Square Polynomial Curve Fit.

```
/FTC      LIST
      C  C** 39299PTX002  CHEN T K             02/02/67 RACS          0001 010 0
      C      LEAST SQUARES POLYNOMIAL CURVE FIT
      C          WITH MODIFICATIONS
      C      THIS PROGRAM WILL FIT ANY POLYNOMIAL FROM 1ST TO 10TH DEGREE, WITH
      C          THE DEGREE SPECIFIED BY THE HEADER CARD, TO BE EXPLAINED
      C      THE PROGRAM USES THE GAUSS-JORDAN METHOD TO SOLVE THE (M+1) NORMAL
      C          EQUATIONS.
      C                LIST OF NAMES OF VARIABLES
      C          NUMBR - THE NUMBER OF X-Y DATA PAIRS, MAX 200
      C          MM    - DEGREE OF THE PLOYNOMIAL, MAX 10
      C          N     - NUMBER OF EQUATIONS (N=M+1)
      C          X,Y   - ARRAYS FOR DATA PAIRS
      C          A     - ARRAY FOR THE SUMS, WHICH BECOME THE COEFFICIENTS OF
      C                  THE UNKNOWNS IN THE SIMULTANEOUS EQUATIONS.
      C          A(I,N+1)ARRAY FOR THE CONSTANT TERMS IN THE EQUATIONS.
      C          C     - ARRAY FOR THE UNKNOWNS, WHICH BECOME THE COEFFICIENTS
      C                  IN THE COEFFICIENTS IN THE POLYNOMISL.
      C          P     - ARRAY FOR THE POWERS OF THE X(I) FROM 1 TO 2M.
      C      TO USE THIS LEAST SQUARES PROGRAM, A HEADER CARD MUST BE PUNCHED
      C      AS FOLLOWS.
      C         COLS. 1-5   DEGREE OF LEAST SQUARES POLYNOMIAL DESIRED
      C         COLS. 6-10  NUMBER OF DATA POINTS TO BE READ IN
      C         COL  15     PUNCH A 1 IF EQUAL WEIGHTING OF DATA IS DESIRED
      C                     PUNCH A 2 IF YOU DESIRE TO READ IN A WEIGHTING
      C                              FACTOR FOR EACH DATA POINT. THE WEIGHTING
      C                              FACTOR IS PUNCHED IN COLS 37-54 OF DATA CARDS
      C         COLS  20    PUNCH A 1 IF YOU -DO NOT- DESIRED THE LEAST SQUARE
      C                              CURVE TO PASS THROUGH ANY PARTICULAR Y-
      C                              INTERCEPT. OTHERWISE PUNCH A 2 AND THE LEAST
      C                              SQUARES CURVE WILL PASS THROUGH THE
      C                              PARTICULAR Y-INTERCEPTS SPECIFIED BY A ZERO
      C         COLS. 21-38 IF YOU PUNCHED A 2 IN COL. 20, PUNCH THE DESIRED Y
      C                              INTERCEPT IN THESE COLS., OTHERWISE LEAVE
      C                              THESE COLS. BLANK.
            DIMENSION X(200),Y(200),A(11,12),C(11),P(20),W(200),YC(200)
            READ (1,200) MM,NUMBR,NSW,INTC,AZERO
        200 FORMAT (4I5,E18.8)
            GO TO (40,80),NSW
         40 DO 111 I=1,NUMBR
        111 W(I)=1.0
            READ(1,110) (X(I),Y(I),I=1,NUMBR)
        110 FORMAT (4E18.8)
            GO TO 41
         80 DO 81 I=1,NUMBR
         81 READ (1,110) X(I),Y(I),W(I)
```

17	18	19	20	21	22
(14)+(15)	D(15)	8I*(17)B00*D(1./BG)	(18)-(19)	(20)/(16)	
208.7168	-9.1802	-7.7090	-14.9688	7.2598	0.0348
347.4932	-3.6338	-2.9252	-8.7311	5.8059	0.0167
478.7217	-6.3436	-5.0003	-11.0364	6.0361	0.0126
620.2786	-4.6258	-3.5880	-10.4795	6.8915	0.0111
726.7224	-4.1589	-3.1795	-10.1214	6.9419	0.0096
808.8416	-2.8327	-2.1385	-9.4961	7.3576	0.0091
854.2280	-1.5854	-1.1824	-9.0495	7.8671	0.0092
798.1277	0.1212	0.0892	-8.5747	8.6640	0.0109
524.8713	8.7337	6.3382	-6.9499	13.2881	0.0253

9	10	11	12	13	14	15	16
BO/BOO	SO	SL	KG/KO	GOR	AVGOR	(13)*(1-I)	BO/BG-RS
0.9307	0.5886	0.7886	0.0862	702.6482	483.6362	193.4545	15.2623
0.9291	0.5717	0.7717	0.1283	976.6760	839.6621	335.8647	11.6284
0.9114	0.5494	0.7494	0.2039	1390.5098	1183.5928	473.4370	5.2848
0.9009	0.5331	0.7331	0.2767	1707.5884	1549.0491	619.6196	0.6591
0.8912	0.5191	0.7191	0.3548	1943.5242	1825.5562	730.2224	-3.4998
0.8807	0.5052	0.7052	0.4496	2132.3469	2037.9355	815.1741	-6.3325
0.8678	0.4902	0.6902	0.5789	2178.3855	2155.3652	862.1460	-7.9179
0.8509	0.4719	0.6719	0.7894	1851.2383	2014.8118	805.9246	-7.7968
0.8058	0.4287	0.6287	1.7708	768.4346	1309.8364	523.9346	0.9369

TABLE FOUR

DEPLETION DRIVE CALCULATION BY THE FINITE DIFFERENCE MATERIAL BALANCE WITH

GAS INJECTION AND CONFORMANCE FACTOR

PRODUCTION GAS INJECTION =0.600

CONFORMANCE FACTOR =0.500

1	2	3	4	5	6	7	8
P	(4)+(5)	DNP	(3)*(1.-E)	DNE	NE	SUM(2)	1.-(7)
800.0000	0.0347	0.0203	0.0102	0.0246	0.1047	0.1950	0.8050
700.0000	0.0168	0.0121	0.0060	0.0107	0.1154	0.2118	0.7882
600.0000	0.0126	0.0095	0.0048	0.0078	0.1233	0.2243	0.7757
500.0000	0.0112	0.0085	0.0043	0.0069	0.1302	0.2355	0.7645
400.0000	0.0096	0.0075	0.0037	0.0058	0.1360	0.2451	0.7549
300.0000	0.0091	0.0072	0.0036	0.0055	0.1415	0.2542	0.7458
200.0000	0.0092	0.0074	0.0037	0.0055	0.1470	0.2634	0.7366
100.0000	0.0109	0.0090	0.0045	0.0064	0.1534	0.2743	0.7257
14.7000	0.0253	0.0224	0.0112	0.0141	0.1675	0.2996	0.7004

16	17	18
800*(15)	(14)-(16)	(17)/(12)
-14.9688	7.2598	0.0390
-8.7311	5.8215	0.0200
-11.0364	6.0835	0.0151
-10.4795	6.9380	0.0132
-10.1214	6.9924	0.0113
-9.4961	7.3969	0.0107
-9.0495	7.8916	0.0108
-8.5747	8.6619	0.0127
-6.9499	13.1231	0.0293

9	10	10A	11	12	13	14	15
GOR	AVGOR	(10)*(1-I)	BO/BG-RS	(11)+(10A)	D(11)	4I*(13)	D(1./BG)
589.5737	427.0989	170.8396	15.2623	186.1018	-9.1802	-7.7090	-12.0619
810.8301	700.2019	280.0806	11.6284	291.7090	-3.6338	-2.9096	-7.0355
1172.7661	991.7981	396.7192	5.2848	402.0039	-6.3436	-4.9529	-8.8932
1448.9170	1310.8416	524.3364	0.6591	524.9954	-4.6258	-3.5415	-8.4444
1656.4346	1552.6758	621.0703	-3.4998	617.5703	-4.1589	-3.1290	-8.1558
1822.2515	1739.3430	695.7371	-6.3325	689.4045	-2.8327	-2.0991	-7.6520
1863.9250	1843.0881	737.2351	-7.9179	729.3171	-1.5854	-1.1579	-7.2921
1583.2512	1723.5881	689.4353	-7.7968	681.6384	0.1212	0.0872	-6.9095
653.2175	1118.2344	447.2937	0.9369	448.2305	8.7337	6.1732	-5.6002

TABLE THREE

DEPLETION DRIVE CALCULATIONS BY THE FINITE DIFFERENCEMATERIAL BALANCE WITH

DISPERSED GAS INJECTION

PRODUCTION GAS INJECTION =0.600

1	2	3	4	5	6	7	8
P	DNP	NP	1.-NP	BO/BOO	SO	SL	KG/KO
800.0000	0.0390	0.1993	0.8007	0.9307	0.5962	0.7962	0.0712
700.0000	0.0199	0.2192	0.7808	0.9291	0.5803	0.7803	0.1054
600.0000	0.0152	0.2344	0.7656	0.9114	0.5582	0.7582	0.1709
500.0000	0.0132	0.2476	0.7524	0.9009	0.5422	0.7422	0.2337
400.0000	0.0113	0.2590	0.7410	0.8912	0.5283	0.7283	0.3015
300.0000	0.0107	0.2697	0.7303	0.8807	0.5146	0.7146	0.3834
200.0000	0.0108	0.2805	0.7195	0.8678	0.4996	0.6996	0.4945
100.0000	0.0127	0.2932	0.7068	0.8509	0.4812	0.6812	0.6742
14.7000	0.0293	0.3225	0.6775	0.8058	0.4368	0.6368	1.5053

TABLE TWO

TABULATION FOR PI AND WELL PRODUCTION - RATE CALCULATION

1	2	3	4	5	6	7	8	9
P	SL	KO	UO	BO	(4)*(5)	(6)O*(3)	(7)/(6)	PI
1500.0000	1.0000	1.0000	1.2100	1.2410	1.5016	1.5016	1.0000	0.5000
1300.0000	0.9499	0.7750	1.2500	1.2170	1.5212	1.1637	0.7650	0.3825
1100.0000	0.8863	0.5750	1.3000	1.1920	1.5496	0.8634	0.5572	0.2786
900.0000	0.8323	0.4570	1.3700	1.1680	1.6002	0.6862	0.4289	0.2144
700.0000	0.8001	0.3860	1.5100	1.1530	1.7410	0.5796	0.3329	0.1665
500.0000	0.7689	0.3380	1.7700	1.1180	1.9789	0.5075	0.2565	0.1282
300.0000	0.7458	0.3050	2.2700	1.0930	2.4811	0.4580	0.1846	0.0923
100.0000	0.7161	0.2660	3.3700	1.0560	3.5587	0.3994	0.1122	0.0561

10	11
NP	Q
0.0	700.0000
0.0441	458.9961
0.1068	278.5962
0.1603	171.5416
0.1926	99.8755
0.2107	51.2966
0.2254	18.4591
0.2418	0.0

17	18
(14)-(16)	(17)/(12)
3.1066	0.0200
3.3777	0.0241
3.7128	0.0293
4.2138	0.0334
4.5784	0.0293
5.6087	0.0241
7.2598	0.0203
5.7535	0.0120
5.9148	0.0095
6.7889	0.0086
6.8388	0.0075
7.2814	0.0073
7.8214	0.0075
8.6677	0.0090
13.5717	0.0224

9	10	11	12	13	14	15	16
GOR	AVGOR	BO/BG-RS	(10)+(11)	D(11)	4I*(13)	D(1./BG)	BOO*(15)
82.8000	85.1000	70.1515	155.2515	-10.0289	-10.0289	-10.5846	-13.1354
78.4000	80.6000	59.7352	140.3352	-10.4163	-10.2079	-10.9473	-13.5856
74.1000	76.2500	50.4461	126.6961	-9.2891	-8.8797	-10.1470	-12.5924
94.9967	84.5483	41.4333	125.9816	-9.0128	-8.3514	-10.1250	-12.5652
152.7850	123.8909	32.3296	156.2205	-9.1037	-8.1312	-10.2415	-12.7096
264.6243	208.7046	24.4425	233.1471	-7.8871	-6.8132	-10.0096	-12.4219
419.7129	342.1685	15.2623	357.4307	-9.1802	-7.7090	-12.0619	-14.9688
513.4541	466.5835	11.6284	478.2119	-3.6338	-2.9776	-7.0355	-8.7311
718.3430	615.8984	5.2848	621.1831	-6.3436	-5.1216	-8.8932	-11.0364
862.8508	790.5969	0.6591	791.2559	-4.6258	-3.6906	-8.4444	-10.4795
968.9006	915.8757	-3.4998	912.3757	-4.1589	-3.2826	-8.1558	-10.1214
1051.1848	1010.0427	-6.3325	1003.7102	-2.8327	-2.2147	-7.6520	-9.4961
1061.9324	1056.5586	-7.9179	1048.6406	-1.5854	-1.2281	-7.2921	-9.0495
882.9209	972.4265	-7.7968	964.6296	0.1212	0.0930	-6.9095	-8.5747
328.6289	605.7749	0.9369	606.7117	8.7337	6.6218	-5.6002	-6.9499

TABLE ONE

DEPLETION - DRIVE CALCULATIONS BY THE FINITE DIFFERENCE BALANCE

1	2	3	4	5	6	7	8
P	DNP	NP	1.-NP	BO/BOO	SO	SL	KG/KO
1400.0000	0.0200	0.0200	0.9800	0.9903	0.7764	0.9764	0.0
1300.0000	0.0241	0.0441	0.9559	0.9807	0.7499	0.9499	0.0
1200.0000	0.0293	0.0734	0.9266	0.9710	0.7198	0.9198	0.0
1100.0000	0.0334	0.1068	0.8932	0.9605	0.6863	0.8863	0.0026
1000.0000	0.0293	0.1362	0.8638	0.9508	0.6571	0.8571	0.0096
900.0000	0.0241	0.1603	0.8397	0.9412	0.6323	0.8323	0.0243
800.0000	0.0203	0.1806	0.8194	0.9307	0.6101	0.8101	0.0486
700.0000	0.0121	0.1926	0.8074	0.9291	0.6001	0.8001	0.0642
600.0000	0.0095	0.2022	0.7978	0.9114	0.5817	0.7817	0.1020
500.0000	0.0085	0.2107	0.7893	0.9009	0.5689	0.7689	0.1365
400.0000	0.0075	0.2182	0.7818	0.8912	0.5574	0.7574	0.1736
300.0000	0.0072	0.2254	0.7746	0.8807	0.5458	0.7458	0.2185
200.0000	0.0074	0.2328	0.7672	0.8678	0.5326	0.7326	0.2791
100.0000	0.0090	0.2418	0.7582	0.8509	0.5161	0.7161	0.3732
14.7000	0.0224	0.2642	0.7358	0.8058	0.4743	0.6743	0.7573

```
              1ION'//)
S.0159     216 FORMAT (//5X'P',8X'SL',8X'KO',8X'UO',8X'BO',6X'(4)*(5)',2X'(6)0*(3
              1)',3X'(7)/(6)',5X'PI'//)
S.0160     217 FORMAT (//4X'NP',9X'Q'//)
S.0161     218 FORMAT (//6X'DEPLETION DRIVE CALCULATIONS BY THE FINITE DIFFERENCE
              1MATERIAL BALANCE WITH'//6X'DISPERSED GAS INJECTION'//)
S.0162     219 FORMAT (//6X'GOR',8X'AVGOR',4X'(10)*(1-I)',3X'BO/BG-RS',2X'(11)+(1
              10A)',6X'D(11)',6X'4I*(13)',4X'D(1./BG)'//)
S.0163     220 FORMAT (//7X'P',10X'DNP',10X'NP',8X'1.-NP',8X'BO/BOO',8X'SO',10X'S
              1L'8X'KG/KO'//)
S.0164     221 FORMAT (//6X'GOR',8X'AVGOR',4X'BO/BG-RS',5X'(10)+(11)',4X'D(11)',7
              1X'4I*(13)',5X'D(1./BG)',4X'BOO*(15)'//)
S.0165     222 FORMAT (//3X'(14)-(16)',3X'(17)/(12)'//)
S.0166     223 FORMAT (//3X'BOO*(15)',3X'(14)-(16)',4X'(17)/(12)'//)
S.0167     224 FORMAT (//6X'DEPLETION DRIVE CALCULATION BY THE FINITE DIFFERENCE
              1 MATERIAL BALANCE WITH',//6X'GAS INJECTION AND CONFORMANCE FACTOR'
              2//)
S.0168     225 FORMAT (//7X'P',8X'(4)+(5)',7X'DNP',5X'(3)*(1.-E)',6X'DNE',9X'NE',
              19X'SUM(2)',5X'1.-(7)'//)
S.0169     226 FORMAT (//5X'BO/BOO',7X'SO',10X'SL',9X'KG/KO',8X'GOR',8X'AVGOR',2X
              1'(13)*(1-I)',4X'BO/BG-RS'//)
S.0170     227 FORMAT (//3X'(14)+(15)',5X'D(15)',6X'8I*(17)','BOO*D(1./BG)',3X'(1
              28)-(19)',3X'(20)/(16)'//)
S.0171     228 FORMAT (6X'PRODUCTION GAS INJECTION =',F5.3,//)
S.0172     229 FORMAT (6X'CONFORMANCE FACTOR =',F5.3//)
S.0173      91 CALL EXIT
S.0174         END
END OF COMPILATION  MAIN    SIZE OF COMMON  00000    PROGRAM  08428
/DATA                                                               ?
```

```
      WRITE (3,208)
      WRITE (3,223)
      DO 63 I=II,NUM
   63 WRITE (3,201) BOG(I),DCB(I),EN1(I)
      IF (E-1.0) 39,91,39
   35 WRITE (3,213)
      WRITE (3,224)
      WRITE (3,228) PGI
      WRITE (3,229) E
      WRITE (3,200)
      WRITE (3,225)
      DO 71 I=II,NUM
   71 WRITE (3,201) PSIA(I),DN(I),SN(I),DNE(I),ENU(I),EN2(I),EN(I,J),
     1DCN(I)
      WRITE (3,202)
      WRITE (3,226)
      DO 72 I=II,NUM
   72 WRITE (3,201) RBO(I),SO(I),SL(I),RPGO(I),GOR(I),AVGOR(I),RAV(I),
     1DOGS(I)
      WRITE (3,209)
      WRITE (3,227)
      DO 73 I=II,NUM
   73 WRITE (3,201) SAGO(I),DDOGS(I),CMDCN(I),BOG(I),DCB(I),EN1(I)
   39 M=M+1
      IF (M-3) 90,90,91
  100 FORMAT (I5,5F10.5)
  101 FORMAT (6F10.4)
  102 FORMAT (4E18.8)
  200 FORMAT (7X'1',11X'2',11X'3',11X'4',11X'5',11X'6',11X'7',11X'8')
  201 FORMAT (8F12.4)
  202 FORMAT (1H1//////7X'9',10X'10',10X'11',10X'12',10X'13',10X'14',10X
     1'15',10X'16')
  203 FORMAT (1H1//////6X'17',10X'18')
  204 FORMAT (//5X'1',9X'2',9X'3',9X'4',9X'5',9X'6',9X'7',9X'8',9X'9')
  205 FORMAT (9F10.4)
  206 FORMAT (////4X'10',8X'11')
  207 FORMAT (1H1///////7X'9',10X'10',10X'10A',9X'11',10X'12',10X'13',10X
     1'14',10X'15')
  208 FORMAT (1H1//////6X'16',10X'17',10X'18')
  209 FORMAT (1H1//////6X'17',10X'18',10X'19',10X'20',10X'21',10X'22')
  210 FORMAT (1H1//////20X'TABLE ONE')
  211 FORMAT (1H1//////20X'TABLE TWO')
  212 FORMAT (1H1//////20X'TABLE THREE')
  213 FORMAT (1H1//////20X'TABLE FOUR')
  214 FORMAT (//6X'DEPLETION - DRIVE CALCULATIONS BY THE FINITE DIFFEREN
     1CE BALANCE'//)
  215 FORMAT (//6X'TABULATION FOR PI AND WELL PRODUCTION - RATE CALCULAT
```

```
S.0074      15 WRITE (3,210)
S.0075         WRITE (3,214)
S.0076         WRITE (3,200)
S.0077         WRITE (3,220)
S.0078         DO 50 I=2,NUM
S.0079      50 WRITE (3,201) PSIA(I),DN(I),EN(I,J),DCN(I),RBO(I),SO(I),SL(I),
              1RPGO(I)
S.0080         WRITE (3,202)
S.0081         WRITE (3,221)
S.0082         DO 51 I=2,NUM
S.0083      51 WRITE (3,201) GOR(I),AVGOR(I),DOGS(I),SAGO(I),DDOGS(I),CMDCN(I),
              1DBG(I),BOG(I)
S.0084         WRITE (3,203)
S.0085         WRITE (3,222)
S.0086         DO 52 I=2,NUM
S.0087      52 WRITE (3,201) DCB(I),EN1(I)
S.0088         WRITE (3,211)
S.0089         WRITE (3,215)
S.0090         WRITE (3,204)
S.0091         WRITE (3,216)
S.0092         DO 40 I=1,NUM,2
S.0093         UOB=UO(I)*BO(I)
S.0094         K=(I+1)/2
S.0095         CPKO=UO(1)*BO(1)*PKO(K)
S.0096         DCU=CPKO/UOB
S.0097         PI=PIO*DCU
S.0098         Q(K)=PI*(PSIA(I)-100.)
S.0099      40 WRITE (3,205) PSIA(I),SL(I),PKO(K),UO(I),BO(I),UOB,CPKO,DCU,PI
S.0100         WRITE (3,206)
S.0101         WRITE (3,217)
S.0102         DO 41 I=1,NUM,2
S.0103         L=(I+1)/2
S.0104      41 WRITE (3,205) EN(I,J),Q(L)
S.0105         IF (PGI) 39,91,39
S.0106      25 WRITE (3,212)
S.0107         WRITE (3,218)
S.0108         WRITE (3,228) PGI
S.0109         WRITE (3,200)
S.0110         WRITE (3,220)
S.0111         DO 61 I=II,NUM
S.0112      61 WRITE (3,201) PSIA(I),DN(I),EN(I,J),DCN(I),RBO(I),SO(I),SL(I),
              1RPGO(I)
S.0113         WRITE (3,207)
S.0114         WRITE (3,219)
S.0115         DO 62 I=II,NUM
S.0116      62 WRITE (3,201) GOR(I),AVGOR(I),RAV(I),DOGS(I),SAGO(I),DDOGS(I),
              1CMDCN(I),DBG(I)
```

```
      DOGS(I)=BO(I)/BG(I)-RS(I)
      DDOGS(I)=DOGS(I)-DOGS(I-1)
      DBG(I)=1./BG(I)-1./BG(I-1)
    9 BOG(I)=BO(1)*DBG(I)
   90 DO 30 I=2,NUM
      J=1
      IF (M-2) 11,21,31
   31 PSI=PSE
   21 IF (PSIA(I)-PSI) 11,29,29
   11 EMM=EN(I-1,J)
      EN(I,J)=(EMM+1.)/2.
   20 DN(I)=EN(I,J)-EN(I-1,J)
      IF (M-2) 12,12,32
   32 DNE(I)=SN(I)*(1.-E)
      ENU(I)=DN(I)-DNE(I)
      EN2(I)=EN2(I-1)+ENU(I)
   12 DCN(I)=1.-EN(I,J)
      IF (M-2) 22,22,33
   33 SO(I)=(E-EN2(I))*RBO(I)*(1.-SW)/E
      GO TO 23
   22 SO(I)=(1.-SW)*RBO(I)*DCN(I)
   23 SL(I)=SW+SO(I)
      RPGO(I)=0.0
      SG=1.-SL(I)
      IF (SG-SOG) 2,1,1
    1 RPGO(I)=EXP(A(1)+A(2)*SL(I)+A(3)*SL(I)**2+A(4)*SL(I)**3)
    2 GOR(I)=RS(I)+BO(I)*UO(I)*RPGO(I)/(BG(I)*UG(I))
      AVGOR(I)=(GOR(I)+GOR(I-1))/2.
      IF (M-2) 13,24,24
   24 RAV(I)=AVGOR(I)*(1.-PGI)
      SAGO(I)=DOGS(I)+RAV(I)
      GO TO 34
   13 SAGO(I)=AVGOR(I)+DOGS(I)
   34 CMDCN(I)=DCN(I-1)*DDOGS(I)
      DCB(I)=CMDCN(I)-BOG(I)
      EN1(I)=DCB(I)/SAGO(I)
      IF (ABS(DN(I)-EN1(I))-0.00005) 5,5,3
    3 EN(I,J+1)=EN(I-1,J)+EN1(I)
      EN(I,J)=EN(I,J+1)
      GO TO 20
    5 IF (M-2) 8,30,30
    8 SN(I)=DN(I)
      EN2(I)=EN(I,J)/2.
      GO TO 30
   29 II=I+1
   30 CONTINUE
      IF (M-2) 15,25,35
```

```
C      (10A)       AVGOR    ((9)(I)+(9)(I-1))/2.
C      (10B)       RAV      (1.-PGI)*(10A)
C      (11)        DOGS     BO/BG-RS
C      (12)        SAGO     (10)+(11)
C      (13)        DDOGS    (11)(I)-(11)(I-1)
C      (14)        CMDCN    (4)(I-1)*(13)
C      (15)        DBG      1.0/BG(I)-1.0/BG(I-1)
C      (16)        BOG      BO(1)*(15)
C      (17)        DCB      (14)-(16)
C      (18)        EN1      (17)/(12)
C      COLUMN      VARAIBLE                 TABLE FOUR
C       (1)        PSIA     RESERVOIR PRESSURE, BASIC DATA
C       (2)        DN       (4)+(5)   DELTA N
C       (3)        SN       DELTA NP (FROM TABLE ONE)
C       (4)        DNE      (3)*(1.-E)
C       (5)        ENU      DELTA NE (ESTIMATE)
C       (6)        EN2      SUM OF (5)
C       (7)        EN       SUM OF (2)
C       (8)        DCN      1.-(7)
C       (9)        RBO      BO(I)/BO(1)
C      (10)        SO       (E-(6))*(9)*(1.-SW)/E
C      (11)        SL       SO+SW
C      (12)        GOR      RS+BO/BG*UO/UG*KG/KO
C      (13)        AVGOR    ((12(I)+(12)(I-1))/2.
C      (14)        RAV      (13)*(1.-PGI)
C      (15)        DOGS     BO/BG-RS
C      (16)        SAGO     (14)+(15)
C      (17)        DDOGS    (15)(I)-(15)(I-1)
C      (18)        CMDCN    (8)(I-1)*(17)(I)
C      (19)        DCB      (18)-BO(1)*(1./BG(I)-1./BG(I-1))
C      (20)        EN1      DELTA  N
       RPGO(1)=0.0
       BG(1)=PA*TF*Z(1)/(PSIA(1)*TA)
       DOGS(1)=BO(1)/BG(1)-RS(1)
       DN(1)=0.0
       SL(1)=1.0
       DN(1)=0.0
       EN(1,1)=0.0
       GOR(1)=RS(1)
       DCN(1)=1.0
       AVGOR(1)=GOR(1)
       RBO(1)=1.0
       SO(1)=1.-SW
       M=1
       DO 9 I=2,NUM
       RBO(I)=BO(I)/BO(1)
       BG(I)=PA*TF*Z(I)/(PSIA(I)*TA)
```

```
S.0005        DIMENSION SN(20),RAV(20),EN2(20),DNE(20)
S.0006        READ (1,100) NUM,SOG,TF,TA,PA,SW
S.0007        READ (1,101) (PSIA(I),BO(I),RS(I),Z(I),UO(I),UG(I),I=1,NUM)
S.0008        READ (1,102) (A(I),I=1,4)
S.0009        READ (1,100) L,PIO,PSI,PSE,PGI,E
S.0010        READ (1,101) (PKO(I),I=1,L)
        C     COLUMN      VARAIBLE              TABLE ONE
        C      (1)        PSIA     RESERVOIR PRESSURE, BASIC DATA
        C      (2)        DN       PRODUCTION INCREMENT
        C      (3)        EN       CUMULATIVE PRODUCTION
        C      (4)        DCN      1.0-(3)
        C      (5)        RBO      BO(I)/BO(1)
        C      (6)        SO       (1.0-SW)*(4)*(5)
        C      (7)        SL       (6)+SW
        C      (8)        RS       BASIC DATA
        C      (9)        GOR      (8)+BO/BG*UO/UG*KG/KO
        C     (10)        AVGOR    ((9)(I)+(9)(I-1))/2.
        C     (11)        DOGS     BO/BG-RS
        C     (12)        SAGO     (10)+(11)
        C     (13)        DDOGS    (11)(I)-(11)(I-1)
        C     (14)        CMDCN    (4)(I-1)*(13)
        C     (15)        DBG      1.0/BG(I)-1.0/BG(I-1)
        C     (16)        BOG      BO(1)*(15)
        C     (17)        DCB      (14)-(16)
        C     (18)        EN1      (17)/(12)
        C     COLUMN     VARIABLE               TABLE TWO
        C      (1)       PSIA        PRESSURE STAGE
        C      (2)       SL        LIQUID ( OIL AND WATER )SATURATION
        C      (3)       KO        OIL PERMEABILITY
        C      (4)       UO        OIL VISCOSITY
        C      (5)       BO        OIL FORMATION VOLUME FACTOR
        C      (6)       UOB        (4)*(5)
        C      (7)       CPKO      UO(1)*BO(1)*PKO
        C      (8)       DCU       (7)/(6)
        C      (9)       PI        PIO*(8)
        C     (10)       NP        NP
        C     (11)       Q         (9)*(10)
        C     COLUMN      VARAIBLE              TABLE THREE
        C      (1)        PSIA     RESERVOIR PRESSURE, BASIC DATA
        C      (2)        DN       PRODUCTION INCREMENT
        C      (3)        EN       CUMULATIVE PRODUCTION
        C      (4)        DCN      1.0-(3)
        C      (5)        RBO      BO(I)/BO(1)
        C      (6)        SO       (1.0-SW)*(4)*(5)
        C      (7)        SL       (6)+SW
        C      (8)        RS       BASIC DATA
        C      (9)        GOR      (8)+BO/BG*UO/UG*KG/KO
```

C. Depletion-drive Calculation by The Finite Difference Material Balance.

```
/FTC      LIST
          C   C** 39301PTX002  CHEN T K              02/02/67 RACS            0002 010 0
          C       DEPLETION - DRIVE CALCULATION BY TNE FINITE DIFFERENCE MATERIAL
          C                   BALANCE
          C       THIS PROGRAM IS SOLVING A DEPLETION DRIVE CALCULATION
          C       M=1 IT IS THE DEPLETION DRIVE CALCULATION WITHOUT GAS INJECTION
          C       THE FOLLOWING INPUT DATA MUST GIVEN
          C       ASSUME INITIAL OIL IN PLACE (N) IS 1, THE CUMULATIVE OIL
          C       PRODUCTION (NP) AND OIL PRODUCED DURING AN INTERVAL (DNP) WILL BE
          C       THE FRACTION
          C       NUM       NUMBER OF DEPLETION STAGES
          C       SOG       THE LOWEST GAS SATURATION THAT MAKES KG/KO OTHER THAN ZERO
          C       TF        FORMATION TEMP.
          C       PA        ATMOSPHERE PRESURE
          C       TA        ATMOSPHERE TEMP.
          C       SW        WATER SATURATION
          C       PSIA      RESERVOIR PRESSURE
          C       BO        OIL RESERVOIR VOLUME FACTOR
          C       RS        GAS SOLUBILITY
          C       Z         COMPRESSIBILITY
          C       UO        RESERVOIR OIL VISCOITY
          C       UG        RESERVOIR GAS VISCOSITY
          C       A         COEFFICIENT OF FUNCTION KG/KO
          C       L         NUMBER OF FLOW RATE WANT TO CALCULATED
          C       PIO       ORIGINAL PRODUCTION INDEX
          C       PSI       THE PRESSURE TO STARTING GAS INJECTION
          C       PSE       STARTING PRESURRE CONSIDER CONFORMANCE FACTOR
          C       PGI       DISPERSED GAS INJECTION
          C       E         CONFORMANCE FACTOR
          C       PKO       OIL PERMEABILITY
          C       BEFORE WE START TO USE THIS PROGRAM WE MUST USE A LEAST SQUARE
          C       PROGRAM TO FIND THE RELATION BETWEEN KG/KO AND LIQUID SATURATION
          C       (SL=SO+SW), TO DESIRED ACCURACY KG/KO=F(A+B*X+C*X**2+******)
          C       AFTER THROUGH WHOLE MATERIAL BALABCE CALCULATIONS A WELL
          C       PRODUCTION RATE IS FOLLOWED, USING THE NP VALUE WE FOUND IN THE
          C       PREVIOUS STEP.
          C       M=2 CERTAIN PERCENTAGE PRODUCED GAS INJECTION IS STARTED WHEN
          C       RESERVOIR PRESSURE HAS DROPPED TO AN ASSIGNED PRESSURE BY PRIMARY
          C       DEPLETION
          C       M=3 USING SAME INJECTION RATIO AND THAT THE INJECTED GAS CONTACTS
          C       ONLY A FRACTION OF THE RESERVOIR, SO THE CONFORMANCE FACTOR (E) IS
          C       LESS THAN 1
                  DIMENSION PSIA(23),BO(20),RS(20),Z(20),UO(20),A(5),RPGO(20),BG(20)
                  DIMENSION DN(20),SO(20),DCN(20),ENU(20),RBO(20),SL(20),GOR(20)
                  DIMENSION AVGOR(20),EN(20,2),DOGS(20),DDOGS(20),SAGO(20),CMDCN(20)
                  DIMENSION DBG(20),DCB(20),EN1(20),UG(20),BOG(20),PKO(20),Q(20)
```

16	17	18	19	20	21
BG	15*16	BT	NP*(BT+17)	BT-BTO	N
0.6650E-02	-0.0166	1.2872	0.0182	0.0183	0.9997
0.7300E-02	-0.0392	1.3120	0.0430	0.0430	0.9999
0.8150E-02	-0.0694	1.3462	0.0772	0.0773	0.9997
0.9100E-02	-0.0797	1.3910	0.1220	0.1220	0.9998
0.1030E-01	-0.0458	1.4515	0.1826	0.1825	1.0004
0.1190E-01	0.0682	1.5360	0.2670	0.2670	1.0000
0.1400E-01	0.3092	1.6540	0.3850	0.3850	1.0000
0.1700E-01	0.7310	1.8290	0.5600	0.5600	1.0000
0.2100E-01	1.3666	2.0790	0.8101	0.8100	1.0001
0.2800E-01	2.4986	2.5190	1.2495	1.2500	0.9996
0.4100E-01	4.7304	3.3960	2.1278	2.1270	1.0004
0.7300E-01	10.5240	5.7470	4.4769	4.4780	0.9998
0.1480E 00	24.6842	11.7080	10.4374	10.4390	0.9999
0.1150E 01	220.1429	102.2000	100.8895	100.9310	0.9996

PRODUCED GAS INJECTION (I) = 0.0

RATIO INITIAL RESERVOIR FREE GAS VOLUME OF INITIAL RESERVOIR OIL VOLUME= 0.0

FRACTION OF PRODUCED GAS INJECTION= 0.0

WATER ENCROACHMENT DURING AN INTERVAL= 0.0

PRODUCED WATER DURING AN INTERVAL= 0.0

9	10	11	12A	12B	13	14	15
GOR	AVGOR	DNP	DGP	DGP*(1.-I)	GP	RP	14-RSO
83.0000	85.5000	0.0144	0.0	1.2277	1.2277	85.5000	-2.5000
78.0000	80.5000	0.0194	0.0	1.5637	2.7913	82.6251	-5.3749
73.0000	75.5000	0.0267	0.0	2.0161	4.8074	79.4796	-8.5204
84.6131	78.8066	0.0325	0.0	2.5637	7.3711	79.2442	-8.7558
104.2190	94.4161	0.0369	0.0	3.4807	10.8518	83.5505	-4.4495
155.5413	129.8801	0.0366	0.0	4.7484	15.6002	93.7270	5.7270
248.1894	201.8652	0.0297	0.0	5.9879	21.5881	110.0840	22.0840
376.0474	312.1182	0.0226	0.0	7.0676	28.6557	130.9977	42.9977
520.5754	448.3113	0.0164	0.0	7.3332	35.9890	153.0745	65.0745
650.2600	585.4177	0.0139	0.0	8.1467	44.1356	177.2348	89.2348
772.2766	711.2683	0.0128	0.0	9.1166	53.2522	203.3763	115.3763
825.0723	798.6743	0.0133	0.0	10.6269	63.8791	232.1640	144.1640
752.3342	788.7031	0.0117	0.0	9.1945	73.0736	254.7856	166.7856
346.3752	549.3547	0.0262	0.0	14.3843	87.4579	279.4287	191.4287

1	2	3	4	5	6	7	8
P	NP	1.-NP	BO	SO	SL	KO/KG	RS
1850.0000	0.0144	0.9856	1.2540	0.9740	0.9740	0.0	83.0000
1700.0000	0.0338	0.9662	1.2390	0.9434	0.9434	0.0	78.0000
1550.0000	0.0605	0.9395	1.2240	0.9062	0.9062	0.0	73.0000
1400.0000	0.0930	0.9070	1.2090	0.8641	0.8641	0.0020	68.0000
1250.0000	0.1299	0.8701	1.1940	0.8187	0.8187	0.0053	63.0000
1100.0000	0.1664	0.8336	1.1790	0.7744	0.7744	0.0137	58.0000
950.0000	0.1961	0.8039	1.1640	0.7374	0.7374	0.0303	53.0000
800.0000	0.2188	0.7813	1.1490	0.7074	0.7074	0.0578	48.0000
650.0000	0.2351	0.7649	1.1340	0.6835	0.6835	0.0967	43.0000
500.0000	0.2490	0.7510	1.1190	0.6622	0.6622	0.1532	38.0000
350.0000	0.2618	0.7382	1.1000	0.6399	0.6399	0.2486	32.0000
200.0000	0.2751	0.7249	1.0750	0.6140	0.6140	0.4352	24.0000
100.0000	0.2868	0.7132	1.0520	0.5912	0.5912	0.7144	16.0000
14.4000	0.3130	0.6870	1.0000	0.5414	0.5414	2.1188	0.0

```
              110X'RP',8X'14-RSO')
 S.0075      207 FORMAT (//8X'BG',8X'15*16',10X'BT',8X'NP*(BT+17)',2X'BT-BTO',2X'N'
                1)
 S.0076      301 FORMAT (//6X'PRODUCED GAS INJECTION  (I)  =',F8.4)
 S.0077      302 FORMAT (//6X'RATIO INITIAL RESERVOIR FREE GAS VOLUME OF INITIAL
                1RESERVOIR OIL VOLUME='F8.4)
 S.0078      303 FORMAT (//6X'FRACTION OF PRODUCED GAS INJECTION=',F8.4)
 S.0079      304 FORMAT (//6X'WATER ENCROACHMENT DURING AN INTERVAL='F8.4,//6X'PROD
                1UCED WATER DURING AN INTERVAL=',F8.4)
 S.0080          CALL EXIT
 S.0081          END
END OF COMPILATION  MAIN     SIZE OF COMMON  00000    PROGRAM  05128
/DATA                                                                      >
```

```
S.0034        DRS(I)=RN(I)-RS(I)
S.0035        DRSG(I)=DRS(I)*BG(I)
S.0036        DD(I)=EN(I,J)*(BT(I)+DRSG(I))
S.0037        DUT(I)=BT(I)-BT(1)
S.0038        W(I)=W(I-1)+(DWE-DWP)
S.0039        RES(I)=(DD(I)-W(I))/(DUT(I)+GC*BO(1)*(BG(I)/BG(1)-1.)+BG(I)*CGP(I)
             1*GCI)
S.0040        IF (ABS(RES(I)-1.)-0.0005) 5,5,4
S.0041      4 IF(RES(I)-1.)7,5,6
S.0042      6 EN(I,J+1)=(EN(I,J)+EMM)/2.
S.0043        EM=EN(I,J)
S.0044        EN(I,J)=EN(I,J+1)
S.0045        GO TO 20
S.0046      7 EN(I,J+1)=(EN(I,J)+EM)/2.
S.0047        EMM=EN(I,J)
S.0048        EN(I,J)=EN(I,J+1)
S.0049        GO TO 20
S.0050      5 ENU(I)=EN(I,J)
S.0051     50 WRITE (3,201) PSIA(I),ENU(I),DNP(I),BO(I),SO(I),SL(I),RPGO(I),RS(I
             1)
S.0052        WRITE (3,202)
S.0053        WRITE (3,206)
S.0054        DO 51 I=2,NUM
S.0055     51 WRITE (3,201) GOR(I),AVGOR(I),DN(I),FGP(I),GPI(I),CGP(I),RN(I),DRS
             1(I)
S.0056        WRITE (3,203)
S.0057        WRITE (3,207)
S.0058        DO 52 I=2,NUM
S.0059     52 WRITE (3,204) BG(I),DRSG(I),BT(I),DD(I),DUT(I),RES(I)
S.0060        WRITE (3,301) PGI
S.0061        WRITE (3,302) GC
S.0062        WRITE (3,303) GCI
S.0063        WRITE (3,304) WE,WP
S.0064    100 FORMAT (I5)
S.0065    101 FORMAT (F10.3,F6.1,F10.4,E15.3,F9.2,F10.3)
S.0066    102 FORMAT (4E18.8)
S.0067    103 FORMAT (7F10.5)
S.0068    200 FORMAT (1H1//////10X'1',10X'2',10X'3',10X'4',10X'5',10X'6',10X'7',
             110X'8')
S.0069    201 FORMAT (8F12.4)
S.0070    202 FORMAT (1H1//////9X'9',9X'10',10X'11',10X'12A',9X'12B',10X'13',10X
             1'14',10X'15')
S.0071    203 FORMAT (1H1//////9X'16',9X'17',10X'18',10X'19',10X'20',10X'21')
S.0072    204 FORMAT (E12.4,7F12.4)
S.0073    205 FORMAT (//7X'P',11X'NP',8X'1.-NP',9X'BO',10X'SO',10X'SL',8X'KO/KG'
             1,9X'RS')
S.0074    206 FORMAT (//8X'GOR',8X'AVGOR',8X'DNP',7X'DGP',5X'DGP*(1.-I)',8X'GP',
```

```
C       (3)      DNP      RESERVOIR STOCK TANK OIL
C       (4)      BO       BASIC DATA, OIL FORMATION VOLUME FACTOR
C       (5)      SO       (3)*(4)*(1.-SW)/BO(1)
C       (6)      S        (5)+SW
C       (7)      RPGO     KG/KO
C       (8)      RS       GAS SOLUBILITY IN OIL
C       (9)      GOR      (8)+(4)*(7)/BG
C      (10)      AVGOR    ((9)(I)+(9)(I-1))/2.
C      (11)      DN       OIL PRODUCTION INCREMENT
C      (12A)     FGD      FRACTION OF PRODUCED GAS INJECTED
C      (12B)     GPI      NET GAS PRODUCTION INCREMENT
C      (13)      CGP      NET CUMULATIVE GAS PRODUCTION
C      (14)      RN       CUMULATIVE AVERAGE GAS-OIL RATIO
C      (15)      DRS      (17)-RS(1)
C      (16)      BG       BASIC DATA, GAS FORMATION VOLUME FACTOR
C      (17)      DRSG     (15)*(16)
C      (18)      UT       TOTAL (TWO PHASE) FORMATION FACTOR
C      (19)      DD       (2)*((18)+(17))
C      (20)      DUT      (18)-UT(1)
C      (21)      RES      (19)/(20)
      BT(1)=BO(1)
      ENU(1)=0.0
      W(1)=0.0
      SO(1)=1.-SW
      GOR(1)=RS(1)
      WRITE (3,200)
      WRITE (3,205)
      DO 50 I=2,NUM
      EM=1.0
      EMM=0.0
      BT(I)=BO(I)+BG(I)*(RS(1)-RS(I))
      J=1
      EN(I,J)=(1.+EMM)/2.
   20 DNP(I)=1.0-EN(I,J)
      SO(I)=DNP(I)*(1.-SW)*BO(I)/BO(1)
      SL(I)=SO(I)+SW
      IF(SO(I)-SGO)2,1,1
    1 RPGO(I)=0.0
      GO TO 3
    2 RPGO(I)=EXP(A(1)+A(2)*SO(I)+A(3)*SO(I)**2)
    3 GOR(I)=RS(I)+RPGO(I)*RUOG(I)*BO(I)/BG(I)
      AVGOR(I)=(GOR(I)+GOR(I-1))/2.
      DN(I)=EN(I,J)-ENU(I-1)
      FGP(I)=AVGOR(I)*DN(I)*PGI
      GPI(I)=AVGOR(I)*DN(I)*(1.-PGI)
      CGP(I)=CGP(I-1)+GPI(I)
      RN(I)=CGP(I)/EN(I,J)
```

```
/JOB      GO                    TK CHEN                                          A
/FTC      LIST
          C  C** 39300PTX002  CHEN T K              02/02/67 RACS          0001 005 0
          C     DEPLETION - DRIVE CALCULATION BY MEANS OF SCHILTHUIS EQUATION
          C     THE SCHILTHUS EQUATION INCLUDES FOUR MODIFICATION.  IF ANY ONE OR
          C     MORE THESE CONDITION IN ONE PROGRAM. JUST PUNCH THE FIRST DATA
          C     CARD AS FOLLOING DETAIL. OTHER WISE PUNCH ZERO ON THAT CARD AT
          C     REQUIRED COLUMNS.
          C     COLS.  1-10  A CONSTANT PERCENTAGE (I) OF THE PRODUCED GAS IS
          C                  INJECTED INTO THE RESERVOIR AND IS UNFORMLY DISPERSED
          C                  THROUGHOUT THE RESERVOIR FLUID.
          C     COLS. 11-20  FOR PRESENCE A GAS CAP (M)
          C     COLS. 21-30  FOR GAS CAP INJECTION OF A FRACTION OF PRODUCED GAS
          C                  WITHOUT DISPERSION INTO THE OIL ZONE.
          C     COLS. 31-40  WATER ENCROACHMENT
          C     COLS. 41-50  WATER PRODUCTION
          C     PGI        PERCENTAGE PRODUCED GAS INJECTED IS UNIFORMLY DISPERSED
          C                THROUGHOUT THE RESERVOIR FLUID
          C     GC         RATIO INITIAL RESERVOIR FREE GAS VOLUME TO INITIAL
          C                RESERVOIR OIL VOLUME
          C     GCI        FRACTION OF PRODUCED GAS INJECTION IN GAS CAP WITHOUT
          C                DISPERSION INTO THE OIL ZONE
          C     WE         WATER ENCROACHMENT DURING AN INTERVAL
          C     WP         PRODUCED WATER DURING AN INTERVAL
S.0001          DIMENSION PSIA(15),BO(15),BG(15),RUOG(15),RS(15),UO(15),BT(15),
               1A(5),RPGO(15),EN(15,15),ENU(15),DNP(15),SO(15),SL(15),GOR(15),
               2AVGOR(15),DN(15),GPI(15),CGP(15),RN(15),DRS(15),DRSG(15),DD(15),
               3DUT(15),RES(15),FGP(15),W(15)
S.0002          READ (1,103) PGI,GC,GCI,DWE,DWP
S.0003          READ (1,100) NUM
          C     NUM        NUMBERS OF DEPLETION STAGES
S.0004          READ (1,101) (PSIA(I),RS(I),BO(I),BG(I),RUOG(I),UO(I),I=1,NUM)
          C     PSIA       RESERVOIR PRESSURE
          C     RS         SOLUTION GAS OIL RATIO (GAS SOLUBILITY IN OIL)
          C     BO         OIL FORMATION VOLUME FACTOR
          C     BG         GAS FORMATION FACTOR
          C     RUOG       RATIO OF OIL AND GAS VISCOSITY
          C     UO         OIL VISCOSITY
S.0005          READ (1,102) (A(I),I=1,3)
          C     A          THE COEFF.OF FUNCTION KG/KO
          C     BT         TOTAL (TWO PHASES) FORMATION VOLUME FACTOR
S.0006          READ (1,103) SGO,SW
          C     SGO        THE LOWEST OIL SATURATION THAT KG/KO IS ZERO
          C     SW         WATER SATURATION
          C     COLUMN      VARIABLE
          C      (1)        PSIA       RESERVOIR PRESSURE, SELECTED
          C      (2)        ENU        CUMULATIVE STOCK TANK OIL PRODUCTION
```

B. Depletion-drive Calculation by Means of Schilthuis Equation and Modifications.

15	16	17	18	19	20	21
BO/BOO	SO	KG/KO	UO/UG	GOR	AVGOR	DG
1.0000	1.0000	0.0	46.0000	88.0000	88.0000	0.0
0.9882	0.9740	0.0	49.0000	83.0000	85.5000	1.2280
0.9764	0.9434	0.0	53.0000	78.0000	80.5000	1.5634
0.9645	0.9062	0.0	57.0000	73.0000	75.5000	2.0172
0.9527	0.8641	0.0020	62.0000	84.6183	78.8092	2.5638
0.9409	0.8187	0.0053	67.0000	104.1808	94.3996	3.4743
0.9291	0.7744	0.0137	72.0000	155.5343	129.8575	4.7530
0.9173	0.7374	0.0303	77.5000	248.1894	201.8618	5.9886
0.9054	0.7074	0.0578	84.0000	376.0474	312.1182	7.0676
0.8936	0.6835	0.0966	91.5000	520.5051	448.2761	7.3292
0.8818	0.6622	0.1533	100.0000	650.5710	585.5381	8.1685
0.8668	0.6399	0.2485	111.0000	771.9065	711.2388	9.0782
0.8471	0.6140	0.4353	125.0000	825.3528	798.6296	10.6629
0.8290	0.5912	0.7145	145.0000	752.4614	788.9070	9.1893
0.7880	0.5413	2.1205	188.0000	346.6489	549.5552	14.4095

8	9	10	11	12	13	14
BO/BG	(8)-RS	NP	DNP	(9)*(10)	DG	1.-NP
208.0327	120.0327	0.0	0.0	0.0	0.0	1.0000
188.5715	105.5715	0.0144	0.0144	1.5163	1.2282	0.9856
169.7260	91.7260	0.0338	0.0194	3.0988	1.5635	0.9662
150.1841	77.1841	0.0605	0.0267	4.6697	2.0172	0.9395
132.8571	64.8571	0.0930	0.0325	6.0338	2.5639	0.9070
115.9223	52.9223	0.1298	0.0368	6.8713	3.4744	0.8702
99.0756	41.0756	0.1664	0.0366	6.8366	4.7533	0.8336
83.1428	30.1428	0.1961	0.0297	5.9112	5.9884	0.8039
67.5882	19.5882	0.2188	0.0226	4.2849	7.0674	0.7813
54.0000	11.0000	0.2351	0.0163	2.5861	7.3291	0.7649
39.9643	1.9643	0.2491	0.0140	0.4892	8.1683	0.7509
26.8293	-5.1707	0.2618	0.0128	-1.3538	9.0782	0.7382
14.7260	-9.2740	0.2752	0.0134	-2.5519	10.6625	0.7248
7.1081	-8.8919	0.2868	0.0116	-2.5503	9.1898	0.7132
0.8696	0.8696	0.3130	0.0262	0.2722	14.4098	0.6870

1	2	3	4	5	6	7
P	RS	BO	BOO-BO	BG	(4)/(5)	D(2)+D(6)
2000.0000	88.0000	1.2690	0.0	0.0061	0.0	0.0
1850.0000	83.0000	1.2540	0.0150	0.0066	2.2555	2.7445
1700.0000	78.0000	1.2390	0.0300	0.0073	4.1096	3.1460
1550.0000	73.0000	1.2240	0.0450	0.0081	5.5214	3.5882
1400.0000	68.0000	1.2090	0.0600	0.0091	6.5933	3.9280
1250.0000	63.0000	1.1940	0.0750	0.0103	7.2815	4.3118
1100.0000	58.0000	1.1790	0.0900	0.0119	7.5630	4.7186
950.0000	53.0000	1.1640	0.1050	0.0140	7.5000	5.0630
800.0000	48.0000	1.1490	0.1200	0.0170	7.0588	5.4411
650.0000	43.0000	1.1340	0.1350	0.0210	6.4285	5.6303
500.0000	38.0000	1.1190	0.1500	0.0280	5.3571	6.0714
350.0000	32.0000	1.1000	0.1690	0.0410	4.1219	7.2352
200.0000	24.0000	1.0750	0.1940	0.0730	2.6575	9.4644
100.0000	16.0000	1.0520	0.2170	0.1480	1.4662	9.1913
14.4000	0.0	1.0000	0.2690	1.1500	0.2339	17.2323

```
S.0056          WRITE (3,200)
S.0057          WRITE (3,204)
S.0058          DO 51 I=1,NUM
S.0059       51 WRITE (3,201) PSIA(I),RS(I),BO(I),DBO(I),BG(I),DBOG(I),DNSB(I)
S.0060          WRITE (3,202)
S.0061          WRITE (3,205)
S.0062          DO 52 I=1,NUM
S.0063       52 WRITE (3,201) RBOG(I),DBOGS(I),ENU(I),DNP(I),CNBOS(I),DG(I),RN(I)
S.0064          WRITE (3,203)
S.0065          WRITE (3,206)
S.0066          DO 53 I=1,NUM
S.0067       53 WRITE (3,201) BOI(I),SO(I),RPGO(I),RUOG(I),GOR(I),AVGOR(I),DG1(I)
S.0068      100 FORMAT (I5,5F10.4)
S.0069      101 FORMAT (F10.3,F6.1,F10.4,E15.3,F9.2,F10.3)
S.0070      102 FORMAT (4E18.8)
S.0071      200 FORMAT (1H1//////7X'1',11X'2',11X'3',11X'4',11X'5',11X'6',11X'7')
S.0072      201 FORMAT (7F12.4)
S.0073      202 FORMAT (1H1//////7X'8',11X'9',10X'10',10X'11',10X'12',10X'13',10X'
               114')
S.0074      203 FORMAT (1H1//////6X'15',10X'16',10X'17',10X'18',10X'19',10X'20',10
               1X'21')
S.0075      204 FORMAT (//7X'P',11X'RS',10X'BO',7X'BOO-BO',9X'BG',6X'(4)/(5)',5X'D
               1(2)+D(6)'//)
S.0076      205 FORMAT (//5X'BO/BG',6X'(8)-RS',8X'NP',10X'DNP',7X'(9)*(10)',6X'DG'
               1,9X'1.-NP'//)
S.0077      206 FORMAT (//5X'BO/BOO',7X'SO',9X'KG/KO',7X'UO/UG',8X'GOR',8X'AVGOR',
               18X'DG'//)
S.0078          CALL EXIT
S.0079          END
END OF COMPILATION  MAIN    SIZE OF COMMON  00000    PROGRAM  03868
/DATA
```

```
      RPGO(1)=0.0
      ENU(1)=0.0
      DNP(1)=0.0
      DG(1)=0.0
      DG1(1)=0.0
      BOI(1)=1.0
      RBOG(1)=BO(1)/BG(1)
      DBOGS(1)=RBOG(1)-RS(1)
      CNBOS(1)=ENU(1)*DBOGS(1)
      RN(1)=1.0
      SO(1)=1.-SW
      GOR(1)=RS(1)
      AVGOR(1)=GOR(1)
      DO 4 I=2,NUM
      DBO(I)=BO(1)-BO(I)
      DBOG(I)=DBO(I)/BG(I)
      DNSB(I)=RS(I-1)-RS(I)+DBOG(I-1)-DBOG(I)
      RBOG(I)=BO(I)/BG(I)
      DBOGS(I)=RBOG(I)-RS(I)
      J=1
      EMM=0.0
      EM=1.
      EN(I,J)=(1.+EMM)/2.
   20 DNP(I)=EN(I,J)-ENU(I-1)
      CNBOS(I)=EN(I,J)*DBOGS(I)
      DG(I)=DNSB(I)+CNBOS(I-1)-CNBOS(I)
      RN(I)=1.-EN(I,J)
      BOI(I)=BO(I)/BO(1)
      SO(I)=RN(I)*BOI(I)*(1.-SW)
      IF (SO(I)-SGO) 2,1,1
    1 RPGO(I)=0.0
      GO TO 3
    2 RPGO(I)=F(D(1),D(2),D(3),SO(I))
    3 GOR(I)=RS(I)+RPGO(I)*RUOG(I)*BO(I)/BG(I)
      AVGOR(I)=(GOR(I-1)+GOR(I))/2.
      DG1(I)=AVGOR(I)*DNP(I)
      IF (ABS(DG(I)-DG1(I))-0.0005) 4,4,5
    5 IF (DG(I)-DG1(I)) 6,4,7
    6 EN(I,J+1)=(EN(I,J)+EMM)/2.
      EM=EN(I,J)
      EN(I,J)=EN(I,J+1)
      GO TO 20
    7 EN(I,J+1)=(EN(I,J)+EM)/2.
      EMM=EN(I,J)
      EN(I,J)=EN(I,J+1)
      GO TO 20
    4 ENU(I)=EN(I,J)
```

X. APPENDIX

A. Tarner's Method of Depletion-drive.

```
/JOB      GO                        TK CHEN                                         A
/FTC      LIST
             C   C** 37882PTZ002  CHEN TU-KAO           01/18/67 RACS            0001 005 0
             C        TARNER'S METHOD OF DEPLETION - DRIVE
 S.0001               F(A,B,C,X)=EXP(A+B*X+C*X**2)
 S.0002               DIMENSION PSIA(15),RS(15),BO(15),RUOG(15),UO(15),SO(15),RPGO(15),
                     1BG(15),DBO(15),DBOGS(15),EN(15,3),DBOG(15),BOI(15),DNSB(15),DG(15)
                     2,DG1(15),D(9),RBOG(15),DNP(15),CNBOS(15),ENU(15),RN(15),GOR(15),
                     3AVGOR(15)
 S.0003               READ (1,100) NUM,SGO,SW
             C       NUM          NUMBER OF STAGES
             C       SGO          THE LOWEST OIL SATURATION THAT KG/KO IS ZERO
             C       SW           WATER SATURATION
 S.0004               READ (1,101) (PSIA(I),RS(I),BO(I),BG(I),RUOG(I),UO(I),I=1,NUM)
             C       PSIA         RESERVOIR PRESSURE
             C       RS           SOLUTION GAS-OIL RATIO (GAS SOLUBILITY IN OIL)
             C       BO           OIL FORMATION VOLUME FACTOR
             C       BG           GAS FORMATION VOLUME FACTOR
             C       RUOG         RATIO OF OIL AND GAS VISCOSITY
             C       UO           OIL VISCOSITY
 S.0005               READ (1,102) (D(I),I=1,3)
             C       D            COEFFICIENT OF KG/KO=EXP(F(SO))
             C      COLUMN       VARIABLE
             C        (1)         PSIA       SELECTED
             C        (2)         RS         BASIC DATA
             C        (3)         BO         BASIC DATA
             C        (4)         DBO        BO(1)-(3)
             C        (5)         BG         BASIC DATA
             C        (6)         DBOG       (4)/(5)
             C        (7)         DNSB       (2)(I-1)-(2)(I)+(6)(I-1)-(6)(I)
             C        (8)         RBOG       (3)/(5)
             C        (9)         DBOGS      (8)-(2)
             C       (10)         ENU        NP ESTIMATED
             C       (11)         DNP        (10)(I)-(10)(I-1)
             C       (12)         CNBOS      (9)*(10)
             C       (13)         DG         (7)(I)+(12)(I-1)-(12)(I)
             C       (14)         RN         1.0-(10)
             C       (15)         BOI        (3)/BO(1)
             C       (16)         SO         (14)*(15)*(1.0-SW)
             C       (17)         RPGO       KG/KO BASIC DATA OR CALCULATED FROM GIVEN FUNCTIO
             C       (18)         RUOG       UO/UG BASIC DATA (OIL AND GAS VISCOSITY RATIO)
             C       (19)         GOR        (2)+(8)*(17)*(18)
             C       (20)         AVGOR      ((20)(I)+(20)(I-1))/2.0
             C       (21)         DG1        (11)*(21)
 S.0006                DBO(1)=0.0
 S.0007                DBOG(1)=0.0
 S.0008                DNSB(1)=0.0
```